OUTPUT ANALYSIS AND COMPARISON OF DEPLOYMENT MODELS WITH VARYING FIDELITY

THESIS

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Abstract

Models are used by several organizations in DoD to evaluate systems and situations about which full information is not otherwise available to assist in planning and decision making. Various types of models are employed, including deterministic spreadsheet models, analytical queuing models, and discrete-event simulations. Each type of model has qualitative benefits and drawbacks compared with the others.

A recent USTRANSCOM study employed several models of differing type to evaluate the ability to deploy a US Army Stryker brigade world-wide within the Chief of Staff of the Army-directed 96-hour timeline. This research uses basic statistical methods to explore the differences in the closure time estimates produced by the previously used models over similar sets of input parameters. This research suggests that the conclusions reached concerning the ability to close deployment within a specified timeline are affected by the model used to evaluate the system. In the course of the research, new models incorporating logic described in previous studies were developed for comparison and recently identified distributions describing aircraft cargo loads and en route ground times were applied. This research also developed evidence to support theories that the constraints which pose the largest obstacles toward meeting Stryker Deployment closure goals are the percent of aircraft required to transit hot cargo pads at en routes and the number of en routes required to be traversed during a deployment.

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Matthew M. Gill

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I. Introduction

Background

Computer simulation is a common planning tool used by several facets of the Air Force and Department of Defense in everyday operations, from forecasting requirements for spare parts to exercising the supportability of Operations Plans Time-Phased Force Deployment Data (TPFDD). Different types of models using widely varying underlying logics are used for different situations, depending on the level of fidelity and detail required. Planners at Air Mobility Command (AMC) and US Transportation Command (USTRANSCOM) have developed various models for analyzing deployment lift capabilities over various networks. Each of these models serves a different purpose and provides different insights when analyzing a deployment scenario. The models used run the gamut from detailed spreadsheet models rooted in deterministic algebraic formulas to complex discrete event simulations that can provide a more detailed rendition of the system and set of circumstances to be modeled.

This research will examine the models and output associated with a 2002 study by USTRANSCOM evaluating the ability of the Interim Brigade Combat Team (IBCT, now know as Stryker Brigade) to meet the goal of deploying anywhere in the world within 96 hours of the first departure from their home base. Several different models were used in this study to gain various insights in the ability of the AMC strategic airlift fleet and the system of world-wide en route bases to support this deployment scenario.

The background for this scenario is the US military's change in force structure since the end of the Cold War coinciding with several changes in policy. One change has been the scaling back of overseas operational bases, including a marked reduction in the number of locations of AMC en-route port functions, the transition to the Expeditionary Air Force, and a refocus on smaller, regional conflicts. Yet as the forward presence of the US military has been reduced, the number of conflicts we have engaged in has risen. The scope of conflicts facing the US military has changed as well. The possible locations and size of force necessary to react to contingencies in today's climate vary widely. The potential enemy for the US is changing, and as seen in the Global War on Terrorism (GWOT), becoming less defined. Battles of the future will be fought on different terrains, and the possible locations throughout the world are numerous. The build-up to battle, as evidenced in Operations Enduring Freedom and Iraqi Freedom (OEF and OIF) are also likely to be very short when compared to other conflicts such as Operation Desert Storm and the Korean and Vietnam Conflicts. US military force is being projected more now than at any other time since before the World Wars (Jones, Orletsky, Pirnie, Vick, 2002: 57).

These shifts gave rise to the need for units that could sustain combat on a heavier scale than light infantry units but be a more rapidly deployable force than heavy armor units. This desire and need for a "middleweight" force has been discussed for some time, and can be read about in works dating to at least 1990 (Mazarr, 1990). Americans are not groundbreaking in their thought on these size units, as the French have been moving in this direction since the mid-80s and the Chadians had success against Libya in 1987 employing middleweight units (Mazarr, 1990). However, it was Operation Desert Storm

that highlighted the operational shortfall of the Army. Congress was briefed in 2001 that, "There is, at present, no rapidly deployable force with the staying power to provide our leadership with a complete range of strategic options" (Jones, and others 2002: 7).

The goal for these type of units, as stated in October 1999 by the Chief of Staff of the Army (CSA) in an issued Army Vision Statement for Army Transformation, is to "… *develop the capability to put a combat force anywhere in the world 96 hours after liftoff – in brigade combat teams"* (Rekamp and others, 2002: 1). Joint Vision 2020 backs up this goal by stating that our Armed Forces are to undergo transformation to become more precise, more lethal, and faster (Jones, and others, 2002). Joint Vision 2020 also discusses the concept of dominant maneuver, which, "For the Army, implies much more rapid arrival in theater than had been achieved previously. It also implies that ground troops must arrive ready to fight without the usual reception, staging, and preparation" (Jones and others, 2002: 5).

In order to test the ability of the Army to meet this deployment timeline and of USTRANSCOM to deliver the forces where needed in the time allotted, several studies have been conducted. Each of these studies used models to simulate deployment of the Stryker Brigade. Actual testing of full deployment of these units over the several situations theorized simply is not feasible due to limits of time, money, and resources (Bower, Halliday, Peltz: 2003; Jones and others, 2002; Rekamp and others, 2002). As mentioned before, this research draws heavily from one study in particular completed in 2002 by a joint team from USTRANSCOM and AMC. In the course of that study, three distinct models were used to simulate and evaluate the abilities of and limitations to deploying a Stryker Brigade via air using current and projected airlift system capabilities.

These models were the IBCT Quick Look Tool (QLT), a deterministic spreadsheet model; Model for Intertheater Deployment by Air and Sea (MIDAS), a discrete event simulation model, and Airlift Flow Model (AFM), a higher-fidelity discrete-event simulation model requiring more detailed input data. Each model was used in a different manner and provided different insights based on its capabilities and limitations.

The primary focus of these models was to evaluate the ability to meet closure time. Closure time, for the purpose of this study, will be defined as meaning the time at which all forces associated with a particular deployment package and required to meet a Theater Combatant Commander's objectives for that force package have arrived and been downloaded at the port of debarkation. Deployment closure is an interchangeable phrase for the purpose of this study. Closure times reported in days are the primary output of each model to be examined. The outputs of each model used in the USTRANSCOM study were reported in the appendices of the study report (Rekamp and others, 2002).

In addition to these three models, this research proposes two models that should lie in between Quick Look and AFM in a continuum of fidelity. The first of these models is a variation of the Quick Look using Decisioneering's Crystal Ball add-in program to Microsoft Excel to add some degree of variability at the fleet level. It will be referred to in this research as the Modified Quick Look Tool. The other model is a very basic discrete event simulation created using Rockwell Software's Arena 7.01 program, and will be referenced simply as Arena model in this work.. The varying insights gained from these models will be the focus of this research effort.

Problem Statement

Mobility planners at many levels repeatedly use models to gain insights into and make assumptions about various possible scenarios. These models range from simple deterministic mathematical models through rather detailed, stochastic discrete event simulators. As the models change, there are generally differences in the outputs, even when similar inputs are used. The purpose of this research is to examine not only these raw output differences over a single scenario involving output from several models, but also to make assessments about the overall insights that can be gained from each model and from comparisons between models. The result of this examination will be observations and statements about how the outputs and assumptions about the real process being modeled change with the differences between representative models.

Research Objective

The main thrust of this work is to answer the following question: how do overall insights into a theoretical real-world scenario change when examined over a series of models of various levels of fidelity? A corollary hypothesis to this question is that of the four models examined in this case, there exists an ordered continuum of fidelity, and that the level of fidelity increases with the amount of variability introduced into the model.

Investigative Questions

In order to build toward answering the overall research question, this research will have to research and answer the following questions and sub-questions:

1. What are the underlying differences between the models being examined?

   1a. What is the algebra behind the overall scenario being modeled?

1b. How does each model treat the algebra differently?

2. What are the raw data outputs from each of these models over the defined scenario sets of inputs?

3. What significant mathematical relationships exist between the outputs of the various models?

4. How do each model and its resulting outputs change the conclusions and assumptions that can be made about the scenario?

5. How can the observations of the relationships between the specific models being studied be applied to relationships of other models and different input scenarios?

Methodology

This study consisted of three related phases of comparison. The first phase consisted of a qualitative comparison of the various models and literature related to these models. The goal of this phase was to understand the underlying differences in the models and their algebra. The results of this portion of the study are discussed in chapter two. This phase also prepared understanding for and set up assumptions as to the expected differences in model outputs. During this phase, common treatments were identified that could be used in comparing outputs from the models.

The next step in this study was to design two additional methods of estimating closure time over the 30 given scenarios, and thus the Modified Quick Look Tool and Arena models were developed. During this step, variation was added to create not only point estimates of closure time but also ranges and confidence intervals. Distributions of

ground times and cargo loads observed in a study of Operation Iraqi Freedom strategic airlift were used to provide this variability (Pelletier, 2004). In the case of modifying the QLT with Crystal Ball, draws were taken randomly from the known distributions and applied across the entire scenario for each model run. Arena models were able to make a distinct draw from a cargo load distribution for each aircraft cycle through the model and a ground time draw for each time an aircraft landed. A basic Arena model was developed, and modified 30 times to replicate the changes not only in the levels of factors for each treatment, but also to reflect the different system of bases each origin-destination pair would be assumed to use.

The final phase includes a series of pair wise mathematical comparisons of the outputs from each model. The goal of this phase is to confirm a mathematical hierarchy of fidelity and identify a mathematical relationship between the inputs levels and the respective related outputs from each model. This step would incorporate linear and non-linear regression methods, including least squares methods and stepwise regression, applied to both the raw data outputs and transformed data ratios.

Assumptions/Limitations

There are several assumptions and limitations to this work, many arising from the use and comparison of models to represent situations that have not yet, nor are likely to ever, occur exactly as modeled. The 2002 USTRANSCOM study listed an extensive set of assumptions about the conditions of the system being modeled; these will be discussed and listed within the literature review (Reckamp and others, 2002). Each model also has its own set of limitations; these will be discussed in chapter two or three depending upon

the model. One key assumption throughout this work is that the outputs from the AFM model are the closest, most accurate results that could be expected were the scenarios modeled to actually occur.

One important limiting factor in this case study is that the 2002 USTRANSCOM study includes just 30 treatments common to both the Quick Look and AFM models. Thus, only 30 data points are available for each model for use in comparison, thus limiting the number of data points that can be used to carry comparisons through all four models. These 30 data points are achieved by adjusting two factors over three treatments, or "deployment cases," over ten separate origin-destination pairs for hypothetical Stryker deployment scenarios. The two factors that are adjusted for the treatments are percent of deploying aircraft requiring the use of "hot cargo" pads through the en route airfield system and number of aircraft available to move the required cargo and personnel (Reckamp and others, 2002).

Implications

The implications for this research would be wide-ranging. Planners and analysts at AMC, USTRANSCOM, and other organizations could be able to apply the results to aid their future studies. The specific results of this study will be able to provide a method for applying a mathematical relationship between lower-fidelity models and higher-fidelity models and to allow for simple method to increase the confidence in the results obtained from simpler models.

Summary

AMC, USTRANSCOM, and other organizations frequently use models to gain insights into a situation. Models are particularly helpful to these organizations in assessing the ability to move cargo throughout the world without going through the involved process of physically moving cargo, aircraft, boats, and personnel. Different types of models with varying levels of complexity and fidelity reveal different types of inferences and findings about a system. The purpose of this research is to study a particular case where models have been used extensively to assess deployment capability, identify how the insights change with the models, and derive a functional relationship between the several models.

II. Literature Review

Chapter Overview

The purpose of this chapter is to two-fold. Primarily, this chapter will describe several of the models and the deployment scenario over which the models are examined. It will explain the logic behind the models and break down the algebra behind not only the models but also the general theory of airlift deployment. Secondarily, this chapter will discuss treatments of mathematical and simulation models and differences in how these different types of models can be used. Also, this chapter will detail what differing kinds of outputs and results can be obtained from each type of model and how they can shape assumptions made about the scenario being modeled.

Stochastic Spreadsheet Models

General Research

The literature reveals that spreadsheet models are widely used to analyze, simulate, and solve many problems throughout a wide range of industries. Spreadsheets by nature are primarily input - equation - output models. Their primary use is for day-to-day analytical tasks (CFO Research Services, 2004). They are generally deterministic in nature, and are easy to manipulate for single-point estimates, and analysis of what-ifs and various changes in scenarios (Lander and Harrison, 2000).   Their utility is that they can perform several calculations, that may otherwise take hours by hand, in a matter of seconds. They can become rather cumbersome when used to model more complex situations and do not conceptually solve any problems that couldn't be solved through manual calculations, even if they can complete the calculations rather quickly (Baudin

and others, 1992; CFO Research, 2004). This research will deal with one spreadsheet model in particular, and address a way of potentially adding variability to a model that has not yet been used in any kind of stochastic manner.

IBCT Quick Look Tool Algebra

The ICBT Quick Look Tool is a deterministic spreadsheet model using Microsoft Excel and Visual Basic for Applications (VBA) macros. It utilizes cycle analysis methods to rapidly compute closure time for a matrix of origin-destination pairs over a set of deployment scenarios. It also uses cycle analysis methodology to determine the constraining factor limiting the system throughput (Reckamp and others, 2002). Cycle analysis as related to deployment modeling focuses on determining the number of complete cycles a single aircraft in a fleet can complete in a day, then extending that through an entire available fleet for movement and multiplying by a payload factor to determine how many short tons or personnel can be moved per day. Based what can be moved each day, calculations are extended to determine how many days it would require to complete all movements with the available fleet (Brigantic and Merrill, 2004). A conceptual example of a notional airlift cycle appears at Figure 1.

In the notional deployment cycle depicted at Figure 1, the strategic lift originates from its home station, picks up cargo and/or passengers at the designated Aerial Port of Embarkation (APOE), stops at an enroute airfield for gas, servicing, and possibly a swap of crew, continues to the Aerial Port of Debarkation for download of cargo, then returns through a choice of routes to the APOE to repeat the cycle as necessary until all cargo and personnel to be deployed have been moved through the strategic airlift system to the APOD, at which point the deployment will be called closed (Brigantic and Merrill, 2004).

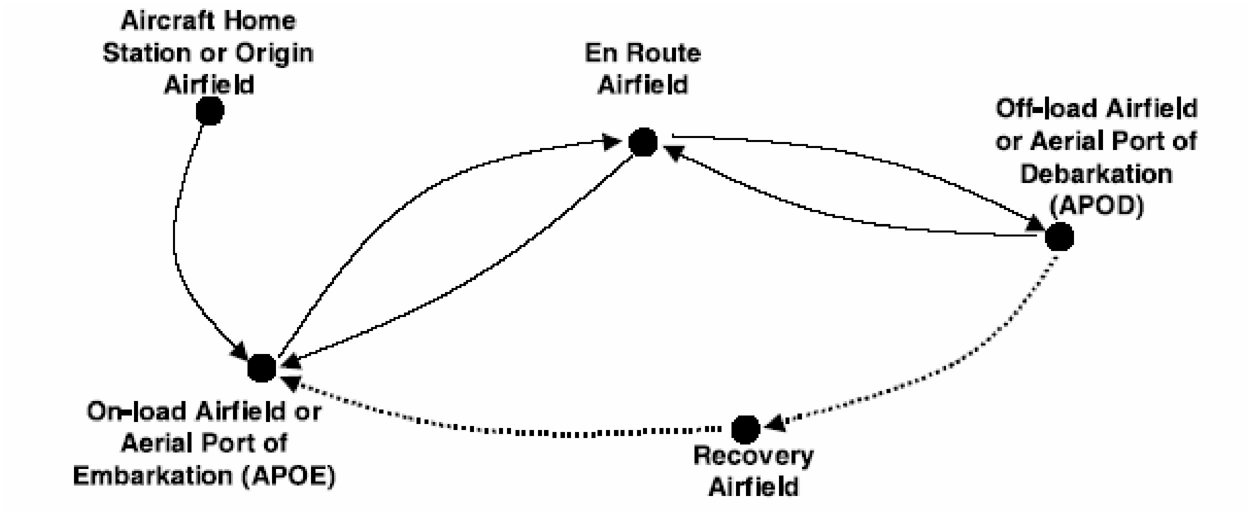


Figure 1. Theoretical Strategic Airlift Cycle (Brigantic and Merrill, 2004: 2)

The Quick Look tool is designed to apply the Algebra of Airlift, as described by Brigantic and Merrill (2004), to several deployment scenarios simultaneously. The main thrust of the algebra is to compute the total time required to complete a round-trip cycle, and then determine how many cycles are required to complete a deployment. The simple equation for cycle time is

$$Cycle\ time = RTFT + TGT \text{ [hrs]}, \tag{1}$$

where RTFT is Round Trip Flying Time and TGT is Total Ground Time. The equations for deriving these variables follow (Brigantic and Merrill, 2004):

$$RTFT = \frac{leg\ dist_1}{block\ speed_1} + \frac{leg\ dist_2}{block\ speed_2} + ... + \frac{leg\ dist_n}{block\ speed_n} \text{[hrs]} \tag{2}$$

and

TGT = on-load time + {(en route ground time) (number of enroute stops in cycle)} + off load time [hrs]. (3)

However, the algebra also considers that there are several other factors which may conspire to constrain the ability to move aircraft through a system in the most efficient manner. To account for these additional possible constraints, the idea of flow interval is introduced. Flow interval is the max of station interval, aircraft allocation interval, and flying hour capability interval. A fourth factor, crew interval, also is in play in the general algebra, but is not considered in the course of this work. Equations for these factors follow (Brigantic and Merrill, 2004):

$$Station\,Interval = \frac{Station\,Ground\,Time}{Station\,Capability}\,[\text{hrs}] \tag{4}$$

$$Aircraft\,Allocation\,Interval = \frac{Cycle\,Time}{Aircraft\,Apportioned}\,[\text{hrs}] \tag{5}$$

$$Flying\,Hour\,Capability\,Interval = \frac{RTFT \times 24}{Ute\,Rate \times Aircraft\,Apportioned}\,[\text{hrs}] \tag{6}$$

$$Flow\,Interval = \max\{(2),(3),(4),\}\,[\text{hrs}] \tag{7}$$

To define these intervals, station interval would be the minimum amount of time required between each aircraft for servicing at an airfield, aircraft allocation interval would be the minimum average time between aircraft cycles, and flying hour capability interval would be the minimum average time between aircraft launches to meet the expected amount of flying hours for a given number of aircraft (Brigantic and Merrill, 2004: 3,4) The flow interval would then be the best interval which could be realized and would represent the most restrictive factor in the system.

Having discovered this restrictor, the algebra can now be used to compute a new closure time with the equation below. In this case, one way en route time is defined as the total ground time and flight time from the time an aircraft begins loading cargo at the APOE through to the time the cargo is offloaded at the APOD (Brigantic and Merrill, 2004, 4).

$$Closure = \frac{(Missions\ Required - 1) \times (Flow\ Interval) + One Way\ Enroute Time}{24} [\text{days}] \quad (8)$$

There are additional equations and factors discussed in the literature relating to other parameters that can be calculated relating to the algebra, such as number of aircraft required or number of short tons per day able to be moved. However, they are not a factor in this research so they will not be discussed. An additional important factor to define that will be discussed is maximum aircraft on ground, or MOG. This value is a function of the ability of an airfield to park, service, and fuel aircraft on station. This is

often a set value for each airfield and defined by most limiting factor on the airfield. Within the algebra construct, a formula is defined for MOG. It is

$$MOG = \frac{Limiting\ Ground\ Time}{Flow\ Interval} \tag{9}$$

One additional factor to be defined that was alluded to above is UTE rate. UTE rate is essentially the number of hours an aircraft can be expected to fly in a 24-hour period. It can be defined and input into a system to test it effect on limiting closure. Otherwise, for the purposes of this study, UTE rate for a fleet is defined as (Brigantic, Merrill, 2004: 6)

$$Ute\ Rate = \frac{RTFT \times 24}{Flow\ Interval \times Aircraft\ \ Apportioned}\,[\text{hrs/day}]. \tag{10}$$

Application of IBCT Quick Look Tool Algebra

The QLT provides both drop-down menus and the ability to manually enter the independent variables used to change the condition over which deployment is modeled. The variables available to change are fleet, percent of aircraft requiring hot cargo parking spots, number of available parking spots and hot cargo parking spots for APOE, APOD, and en routes, as well as total cargo movement requirement and a queuing efficiency factor. The user also has the ability to define the aircraft block speeds, distance between origins and destinations, aircraft cargo payloads, UTE rates, aircraft ground times, and

the aircraft fleets on embedded spreadsheets. Once the user has defined all variables and parameters of a scenario for execution, Quick Look follows the following steps, as outlined in Mahan and others (2004), to compute a closure time for each origin-destination pair.

(1) Compute cycles per day per aircraft.

(2) Compute STONS per day per aircraft by multiplying cycles per day per aircraft by aircraft payloads.

(3) Compute fleet potential STONS per day by multiplying STONS per day per aircraft by the number of aircraft for each aircraft type then summing the totals for each aircraft type in the fleet.

(4) Compute potential fleet closure time from wheels up to wheels down by dividing the movement requirement in short tons by short tons the fleet can move per day and adding an adjustment for delay until the first aircraft arrives.

(5) Compute the total MOG required at APOD and APOE to optimize fleet potential by the following expression:

$$\frac{\{(cycles/day/aircraft)\times(\#aircraft\ in\ fleet)\times(ground\ time)\}}{24} \qquad (11)$$

(6) Compute the hot cargo MOG required at APOE and en routes to optimize the fleet potential by the following expression:

$$\frac{\{(cycles/day/aircraft)\times(\#\,aircraft\ in\ \ fleet)\times(\%\ HCP^{*})\times(ground\ \ time)\}}{24} \qquad (12)$$

* % HCP = percentage of aircraft requiring hot cargo parking spots

(7) Compute constrained throughputs, similar to identifying the flow interval, through the following relationship:

If (scenario MOG at a node) < (MOG Requirement at node), then MOG constrained throughput = (available MOG)/(required MOG) × fleet potential throughput (short tons) per day (13)

(8) Identify the limiting factor based on the input variable constraint that minimizes throughput.

(9) Finally, compute constrained closures from wheels up to wheels down based on the limiting factor by dividing the movement requirement in short tons by the constrained amount of short tons the fleet can move per day and adding an adjustment for delay until the first aircraft arrives.

Crystal Ball

Crystal Ball is a program created and licensed by the Decisioneering Corporation as an add-in to Micorsoft's Excel spreadsheet program. It adds the ability to provide Monte Carlo functions within spreadsheet models (Lander and Harrison, 2000). It does so by making random draws from defined distributions from set cells, then applying those

random draws into a user-defined formula in order to produce a one-trial result for a defined forecast cell. Crystal Ball can then repeat the process rapidly, capturing all the results from each defined forecast cell. Crystal Ball can then produce several outputs, including detailed statistics, frequency charts, flexible user-defined reports, sensitivity analysis, and trend charts. Data can be exported from Crystal Ball directly to Microsoft Excel.

Discrete Event Simulations

General Research

The general concept of discrete-event simulations is a relatively simple one. Similar to movements around a board game, these simulations involve modeling a system as it evolves over time by representing variables changing and events happening instantaneously at separate points in time (Law and Kelton, 2000; Baudin and others, 1992). Instead of using a mathematical equation to determine an estimate of simulation as in spread sheet models, discrete-event simulators make an attempt to actually run through a simplified version of the real process and record data about the system and events as things happen in simulated real-time. This allows for the introduction of variability as events can be set to happen or behave according to user-defined probability distributions. The key to simulation models is that while they exercise at the entity level, they are exploring and simulating the relationships and interdependencies of the several operators, events, and entities in the system (Baudin and others, 1992).

The dynamic nature of discrete-event simulations requires the model to keep track of the current simulated time at all moments within the model run. This is done through

the use of a simulation clock, although there is generally no relation between a simulation time and time required to run a model. (Law and Kelton, 2000: 7).

Discrete-event simulations can utilize either an event-scheduling approach, wherein the "times of future events are explicitly coded into the model and explicitly scheduled to occur in the simulated future" (Law and Kelton, 2000: 11), or a process approach, in which the code describes the experiences of the entity as it cycles through the defined system. The process approach was used in building the proprietary model in Arena for this study.

Airlift Flow Model (AFM)

The Airlift Flow Model (AFM) was a model that included great system detail and was a large simulation of the global, wartime mobility system. AMC Studies and Analysis Flight was the primary owner of this model. It was a data driven model that depended upon a detailed movement requirements file for passengers and cargo as input (Reckamp and others, 2002). It was comprised of over 60,000 lines of code in various programming languages (Browne, 2000). It has since been primarily replaced by other models compliant with the Air Force's High Level Architecture.

In AFM, aircraft were individually loaded by piece from very detailed data entered in a specific format. The piece-by-piece loading of the aircraft facilitated an estimate of the average amount of cargo that could be loaded on each aircraft in the Stryker Brigade deployment scenario. One iteration of AFM was thus run and completed prior to the exhaustive scenario examination with Quick Look. The average cargo loads from these runs were then substituted in several of the scenarios examined in place of the AFPAM 10-1403 mandated planning factors. Once the aircraft were loaded with

passengers and cargo, the aircraft were made to compete for resources and service as they delivered cargo through a deployment scenario (Reckamp and others, 2002).

AFM added a great deal of realism to the scenarios modeled in comparison with Quick Look. It simulated individual aircraft, infrastructure, airfields, service capabilities, and fuel resources globally. It also applied distributions describing maintenance reliability rates and repair times for aircraft. Aircraft performance, ground times, and cargo capacities were represented for each aircraft type.

Arena

Arena is a commercially available simulation software program licensed and distributed by the Rockwell software corporation, and is a "true Microsoft Windows operating system application" (Kelton and others, 2004: 49). It allows the analyst to build and run models as simple or as detailed as is desired. Arena uses, "interchangeable templates of graphical simulation modeling and analysis modules that you can combine to build a fairly wide variety of simulation models" (Kelton and others, 2004: 12). Arena allows for hierarchical models to be constructed. All actions are governed by distributions, attributes, and variables that can be programmed by the analyst. It is a mechanistic simulation, meaning that individual operations throughout a given system happen (with respect to order and time) as they would in reality (Kelton and others, 2004).

There are seven basic groups of parts in the Arena simulation. The entities are the items that move around through a designed system. They are the dynamic objects in the system, and in this study they will represent the aircraft. The attributes are common characteristics ascribed to entities. As each attribute is assigned to an entity, it stays with

that entity throughout the model run until it is changed through another assignment module. The variables in Arena are global, and each reflects some characteristic of the system as a whole. For instance, a variable may be used to track cargo moved or system time. Resources represent items used to service entities, and when a resource is being used, it is seized, and then released once an entity has finished its use of the entity. Queues build around resources as they wait to use the resource that another entity is already busy using. Statistical accumulators gather data and track performance measures about just about everything happening in the system. They provide the data that is available in many forms in various reports once a simulation is completed (Kelton and others, 2004). The final, most important part of the discrete-event model is the event. An event is defined in Arena as, "anything that happens at an instant of simulated time that might change attributes, variables, or statistical accumulators" (Kelton and others, 2004: 27).

The output data captured by Arena is very extensive. Mean times, numbers, ranges, percent time in use, and queue size are just the tip of the surface of outputs available. Arena can display output in either plain text form in notepad or database from in an application of Microsoft Access.

Relevant Research

IBCT and other Stryker Deployment Studies

The literature reveals that several studies have been completed to assess the ability to deploy the Stryker Brigade within it prescribed timeline. All have assessed that under current conditions and with the current composition of the Stryker Brigades, the

goal of 96-hour deployment is not feasible (GAO, 2003; Bower and others, 2003; Jones and others, 2002, Reckamp and others, 2002). The particular study which will be the basis for this research is the 2002 USTRANSCOM study that used several different models to exhaustively examine alternatives to the status quo that may allow Stryker to meet its deployment timeline.

For the purposes of their study, the USTRANSCOM team used two established deployment simulation models and a spreadsheet deployment model developed by USTRANSCOM to estimate deployment closure. It is important to keep in mind throughout this research that the Quick Look Tool (QLT) developed by the USTRANSCOM study team was not intended to be the 100% solution for simulating Stryker Brigade or other deployments via air. It was intended to quickly make closure estimates for several scenarios simultaneously and provide information relating to the limiting factors for each deployment scenario. After several iterations had been examined using the QLT, certain scenarios and origin-destination pairs were chosen for more detailed examination with AFM and MIDAS models. The decisions about which treatments to examine further were based on several factors, including results from QLT suggesting which changes to the deployment scenarios would yield results in the effort to reduce deployment closure times and meet the 4-day deployment closure goal. The several combinations of factors that were studied for further in-depth analysis were named by case. The initial case including assumptions that no changes would be made from the current deployment state was labeled the baseline case. Two other cases that were exercised using all models were identified, and will be referred to in this research, as cases D and I (Reckamp and others, 2002).

In the course of their study, the USTRANSCOM team identified several assumptions about the system they were evaluating which have been carried over into this work. The list of assumptions is:

- The Stryker Brigade is the primary airlift claimant in a surge operation using FY 05 C-5s and C-17s. The airlift fleet does not include aircraft withheld for high priority missions, training aircraft, etc.
- No C-130s used in strategic deployment.
- FY 05 infrastructure including completion of JIWG recommended projects at the APOEs to support 20 minute departure interval
- Army will maintain passenger and cargo flow to meet deployment timelines
- Unit integrity modeled at a company level without sequencing priority
- Unit Basic Load uploaded on vehicles
- 50% of deploying aircraft have hot cargo (i.e. ammunition in quantities and/or with hazardous classification that requires loading at a specified safety distance from buildings or aircraft) restricted loads in the baseline scenario
- Augmented air crew for extended duty up to 24 hours
- Sufficient reserve augmentation is available to provide timely support for increase airlift requirements
- Used most direct route for overflight rights
- Required diplomatic clearances are in place or granted immediately to include all overflight and basing rights
- All foreign and US airfield operation quiet hours are waived
- APOD is a benign environment - AMC Threat Working Group assessment that APOD is safe to operate
- Consolidated APOD maximum working MOG of 7 with no hot cargo restrictions and multiple APODs available
- No aircraft refueling at APOD to preserve in theater fuel for Army operations. Aircraft refueled at the recovery airfield after the APOD.
- Returning aircraft have no hot cargo and therefore no hot cargo restrictions
- Surge utilization rates in accordance with Air Force Pamphlet (AFPAM) 10-1403
- Standard ground times for all on-load and en route stops. Expedited for off-load operations. All ground times in accord with AFPAM 10-1403*
- Weather is not a mitigating factor

(Reckamp and others, 2002: 5, 6)

* Modified in this study as described in table 1

Model Comparisons

Models have been compared before in several studies. However, most writings deal with either validating one model in comparison with another or discuss qualitative comparisons between different model types. The literature reveals several alternatives for simulation comparisons, including gaining feedback from users, use of expert opinion, and model-to-model comparisons (Hicks and Long, 1992: 24). As the thrust of this research is not to make qualitative comparisons, but simply to make quantitative observations regarding the outputs of different types of models, model-to-model comparison methods hold the most value for this research.

One example of model-to-model comparisons is the September 1987 effort by Gregg Clark, titled "The Theater Simulation of Airbase Resources and Logistics Composite Models: A Comparison," consisted of a statistical analysis using a randomized block design with two dependent variables while adjusting only one independent variable, and used nearly identical input databases. He concluded that there were statistically, "no significant differences in the results of the two models" (Hicks and Long, 1992: 25).

A second notable effort was conducted in 1991, by David Leonhardt, titled *A Comparison of the All Mobile Tactical Air Force and Logistics Composite Simulation Models*. He used a similar design and again found the two models in his study to produce statistically similar results.

A third follow-on study conducted by Heston Hicks and Lawrence Long in 1992, titled *A Methodology for Model Comparison Using the Theater Simulation of Airbase*

Resources and All Mobile Tactical Air Force Models, discussed these and other studies and developed a detailed methodology for making a full comparison of models using qualitative and quantitative aspects. The results of this study detailed statistical methods, including means testing of outputs and comparison of confidence limit estimates, useful in comparing models. He also continued to stress the importance of qualitative measures when assessing the effectiveness of models for use in the Air Force (Hicks and Long, 1992).

A more recent study conducted in 2000 by Ken Browne, titled *Using RSM, DOE, and Linear Regression to Develop a Metamodel to Predict Cargo Delivery of a Time Phased Force Deployment Document* [sic] focused on regression techniques and other methods to create a meta-model of a detailed model. In the course of his work, he also made detailed tests about the differences in output between his new meta-model and the full version of the model (Browne, 2000). His methods leading to the conclusion that the outputs of the tow models were nearly identical will also be helpful in guiding this work as an attempt is made to compare different types of models that will not have similar data input methods.

The most recent and most relevant comparison was a 2001 study by Julien Granger, Ananth Krishnamurthy, and Stephen Robinson, titled "Stochastic Modeling of Airlift Operations." This study made statistical comparisons of mean outputs of two proprietary approximations of AFM, one being a simulation model and the other being a deterministic network approximation model. This study used a full 2^4 factorial design to measure the effects of variability, ramp space, flying times, and ground times. The purpose of this study was to observe and measure the effects that allowing certain

parameters, in this case flying times and ground times, vary in one model while being treated deterministically in another model. Several insights were derived from this study. Two key insights were that increasing variability in modeling increased the time required to complete a cargo movement, and that adding aircraft had a decreasing effect on improving airlift completion time (Granger and others, 2001). Similar methods as were used in this 2001 study will be applied in this work.

Payload and Ground Time Distributions

Standard planning factors for ground times and aircraft loads may or may not be the best factors for using in planning or modeling airlift. One study conducted by Dana Pelletier in August 2004 suggests that, in fact, the actual ground times at en route locations deviate upward from the scheduled ground times by a factor governed by a separate set distribution each for the C-17 aircraft and for the C-5 (Pelletier, 2004). The same study also suggests that aircraft payloads typically fall short of the AFPAM 10-1403 planning factors for weight, and proposes a set of distributions to describe the expected short ton payloads for both C-17 and C-5 aircraft. These distributions are displayed at Table 1.

Table 1. Deployment Distributions

Aircraft	Payload Distribution	Ground time distribution
C-5	Normal (49.9, 12.9)	scheduled + Lognormal (1.27, 1.62)
C-17	Normal (28.8, 9.9)	scheduled + Lognormal (0.916, 1.38)

(Pelletier, 2004)

In order to maintain fidelity with the studies that have been previously completed, these distributions will not be applied in full in the models created by the researcher for this study. Instead, the deviations from the mean will be applied to the means for payload and ground times used in the USTRANSCOM study.

Summary

The review of literature has provided a broad base from which to build this research. It provided the beginning from which to build a detailed study into the differences between the models and examine how newly proposed distributions may affect the outcomes. The case being analyzed has been discussed, the types of models being analyzed have been explained, new distributions to be applied to the algebra have been introduced, and the algebra behind the models has been examined.

III. Methodology

Chapter Overview

The purpose of this chapter is to detail the methods used to answer the question of how overall insights into a theoretical real-world scenario change when examined over a series of models. The first step, as in any problem, is to define the problem at hand. The two sections following will discuss the models created in the course of this study. The fourth section will lay out all assumptions that have been made in this research in addition to those which were carried over from previous works and outlined in the literature review. The next two sections will define the variables of interest in this work and the data input into the models. Once the problem, models, assumptions, variables, and data have been described, description of the methods used in the pair wise comparisons between AFM and the other models will follow. Finally, any additional insights will be discussed.

Definition of the Problem

Before a problem can be properly explored, it must be fully explained to and understood by the analyst. In the case of this research, the problem evolved over time and a series of discussions with many outside agencies, including representatives from AMC, USTRANSCOM, European En-route Steering Committee, McChord AFB Aerial Port, and Ft. Lewis Logistics and Combat Plans. Through thorough inspection of previous works and lengthy discussion, it was determined that the most useful result of study would be to examine the relationship between the models used in examining the ability to meet the goal of deploying the Stryker Brigade within 96 hours. Whereas

studies have been made comparing the benefits and drawbacks of spreadsheet models against other models, few if any have quantitatively investigated the differences of the outputs produced by these different types of models when exercised over a similar set of input parameters (Baudin and others, 1992; Harrison and Lander, 2000)

The most direct question of concern is regarding the insights yielded by each model. Specifically, the focus was to identify if and where the insights into the ability to meet the closure goal may change as different models are used to assess the ability of the system. To clarify, the goal was to determine if there were situations where one model may predict that closure could be reached within the desired time frame while other models may determine that closure within the specified time window was not attainable.

The Models

Modified Quick Look Tool

As discussed in the literature review, the IBCT Quick Look Tool is a detailed deterministic spreadsheet model capable of simultaneously computing closure for several origin-destination pairs over a set of defined inputs applied to all pairs. This tool provides as output only a point estimate of the time required to complete a deployment, without any particular level of confidence about that estimate (Mahan, J.M., W.H. Key II, R.T. Brigantic, and K Rekamp, 2004).

For this study, a level of variance has been injected into the QLT with the introduction of Crystal Ball and the subsequent creation of the Modified Quick Look Tool. Crystal Ball, applied in the course of this study, would for each replication of the simulation be called on to make one random draw from a user-defined distribution for

each variable defined to be stochastic. As the value from this draw was then held constant and applied across fleet level calculations, this model can be described as fleet-level stochastic.

For the purposes of this study, only two of the defining variables were made to vary with each computation of closure. These two variables were payload and en route ground times. The basis for allowing these two particular variables to vary was the work by Maj Pelletier (2004); discussed in the literature review, suggesting that enroute ground times and cargo payloads follow specific distributions when operating in strategic combat lift operations. For the purpose of this study, one important deviation from his findings was carried throughout the model runs. Where his work suggested that the mean payloads for C-5 and C-17 aircraft were 48.98 and 28.75 short tons, respectively, this study continued to use the means reported in the 2002 IBCT study of 77.9 and 56.9, respectively. These means were gathered from simulated aircraft loads incorporated in initial runs of the AFM model (Reckamp and others, 2002). Pelletier's reported standard deviations from the mean were then directly applied to these means to form the distribution from which Crystal Ball made draws for each run.

When this model was run, all ten origin-destination pairs were modeled simultaneously. Once the variables of fleet composition and percent of aircraft requiring hot cargo pads was set, Crystal Ball created and recorded statistics from 1,000 trials for each origin-destination pair. For each trial, draws were made for C-5 and C-17 aircraft loads and ground times, and the results of draws were applied to the fleet level for each origin-destination pair simultaneously.

Arena 7.01

Arena allowed the study to bridge between the deterministic, algebra-driven spreadsheet models and the fully stochastic detailed discrete event simulation of AFM. In the case of this study, the Arena model built was not as detailed as AFM, however, it did move beyond the algebraic spreadsheet-based models to provide significant levels of discrete event simulation and queuing within the system. As with the Modified QLT, only two inputs into the system were treated stochastically: aircraft loads and ground times. These variables were assigned the same distributions as in the Modified QLT. However, Arena presented more challenges in that due to the way the general model was constructed, nodes had to be added or removed and definition of time values and resources had to be adjusted for each model. A separate model branching from the basic model was thus created, run, and recorded for each treatment.

A sample of the basic model is displayed at Figure 2. In this model, the entities created are the cargo aircraft, and enter the system from the upper-left hand modules, subsequently moving through the model clockwise. They are created once every twenty minutes, are assigned an aircraft type, and then, if there are at least 50 short tons of cargo remaining to be moved from the APOE, they are assigned several attributes, including the amount of cargo they will carry and the time they will spend on the ground being serviced at each en route stop. After this set of assignments, the aircraft flow through a circuit representing a fixed route based upon data from the 2002 study at Appendix C. Delay nodes represent block time between airfields, and seize/delay/release nodes represent airfields. After the APOD, the system is again tested to see if cargo remains to be moved from the APOE. If not, the entity leaves the system, otherwise, it "flies" a

retrograde route back to the decision point to see if cargo remains once the aircraft reaches the APOE. If so, then all attributes are re-assigned and the trip begins again. Otherwise, the entity leaves the system. When the last entity leaves the system, the model terminates and the chief variable of interest, closure time, is recorded.

As each origin-destination pair required a separate model for simulation in Arena, each origin-destination pair was modeled independently of the others. In order to keep fidelity with the Modified QLT, each treatment was accorded 1,000 trial runs and Arena gathered and calculated resultant statistics. However, to ensure that the results were not affected by initialization effects, the system was reset to default seeds from which to begin draws for each set of trials. Warm-up periods were not considered as a steady-state system was not being modeled, and all statistics were cleared and reset prior to each trial. A representative model layout is pictured at Figure 2, while representations of the model for each origin - destination pair are included at Appendix C.

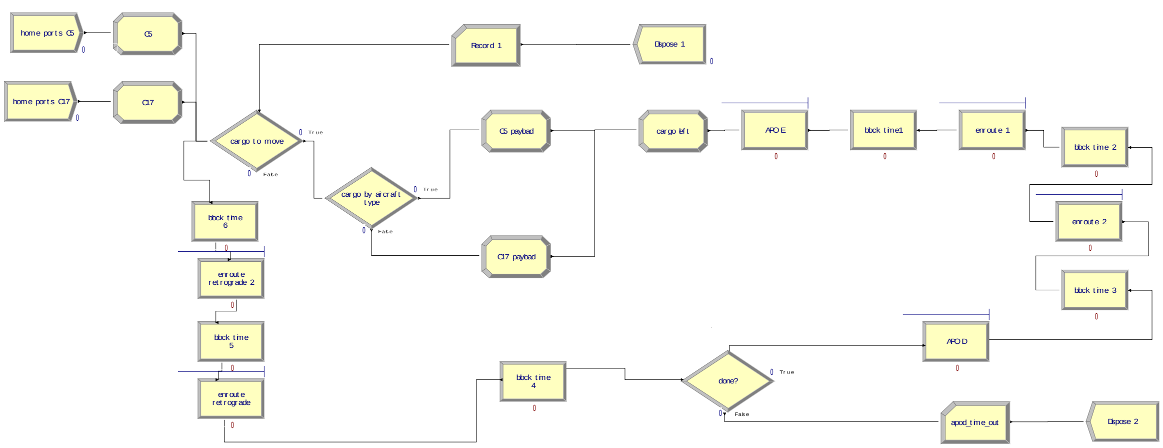


Figure 2. Arena Model Sample

Assumptions

There are several assumptions to be made in this study in addition to those carried over from the 2002 study and detailed in the literature review. These assumptions and the rationale behind them for this thesis effort are listed below.

1. The first assumption that gives rise to all comparisons made and is the basis for all observations is that AFM output is the "truth" against which other models are measured. That is, that the output from AFM as reported in the 2002 USTRANSCOM study are treated, for this study, as being fully accurate. This is necessary as there is no possible way to physically conduct the actions being modeled, as such a set of repetitive deployments would be both time-consuming and exorbitantly expensive. One could argue that other models may be more accurate, but for the purposes of this study, the data at hand will be used. AFM is sufficiently detailed in its replication of events for this to be a reasonable assumption.

2. The distributions for ground times defined by Maj Pelletier (2004) and used in the Modified QLT and Arena will be those that describe the operations at en route bases on both outbound and retrograde journeys of aircraft. This is a reasonable assumption based on the most recent data and study available when conducting this study.

3. Aircraft will be modeled flying a single, consistent, fixed route for each origin-destination pair. While this scenario may be unlikely to hold for every aircraft flight in the number it would take to transport the amount of cargo associated with this study, it is reasonable in this thesis. This assumption was implied in the methodology of the QLT (Mahan and others, 2004) and through the outline of the theoretical routes in the 2002

study (Key, 2005; Reckamp and others, 2002). To deviate from this assumption would make comparing models less meaningful.

4. Aerial refueling is not considered for the purpose of this study. While some reported results from previous studies included the effects of including aerial refueling, none of the reported treatments common to both Quick Look and AFM included aerial refueling.

5. Personnel and equipment will be available to support the infrastructure as defined in each model or set of models. This is an extension of assumptions made in the USTRANSCOM study that the AMC Global Reach Laydown initial enabling force structure is deployed and in place before the commencement of deployment operations for the Stryker Brigade. Any lack of personnel or equipment shortage is assumed to be captured in the enroute ground time distributions as defined by Maj Pelletier.

Definition of Variables

The primary dependent variable examined throughout this work is the closure time output from each model. This variable is defined to be the time at which all cargo had successfully reached the APOD and been offloaded from aircraft. For the purpose of being able to carry comparisons through all the models at the same treatment, the factors and treatments to be used were limited by what was recorded and reported from the 2002 USTRANSCOM IBCT study. Only two factors other than origin-destination were varied in common over the course of the 2002, and thus this, study, and the full factorization of these two factors was not reported for all models. The result was a total of only three cases were applied to each of ten origin-destination pairs using both the QLT and AFM.

Thus, a total of 30 treatments provide common points of comparison over which to assess the differences in insights from these models. The independent variables in this case were the percentage of aircraft requiring hot cargo pads, which had two levels, and the size of the aircraft fleet, with three levels.

Input Data

Data was only required to be input for the two models created in the course of this study. As discussed in the literature review, for Modified QLT, all data bar those distributions mentioned above were already included in the tool as created by USTRANSCOM. However, the proper choices for all available variables had to be chosen before running each iteration of the model. In the case of the Arena model, data had to be calculated and input for the following independent variables: flying time between airfields, number of airfields used per origin-destination pair, effective number of aircraft parking spots per airfield, and number and type of aircraft per fleet. All expressions bar flying time between airfields were available in the USTRANSCOM study (Reckamp and others, 2002: 42). To derive flying time between airfields, a chart embedded in the QLT was used to determine the speed at which the aircraft would be flying, and the USTRANSCOM study listed the distance for each leg in the defined routes. This allowed for the calculation of flying time (FT) through equation 14.

$$FT = \frac{leg\ dist}{block\ speed} \tag{14}$$

Output Analysis

The output available for analysis ranges from the extensive and detailed outputs generated by Arena and the Modified QLT through Crystal Ball to very limited point estimates available from AFM. This data did lend itself, however, to several methods of investigation in searching for insights to the relationships between the models. The evaluation method of each model was to compare its output over the 30 available treatments to those from AFM. This was done in a technique similar to evaluating forecast methods. AFM output data was treated as the "actual" and the output data from each model was treated as a forecast. First, error terms for each model compared against AFM were calculated. The models were then compared against each other based on these error terms. Once this comparison was completed, each model was evaluated on the basis of whether or not its estimates were conservative compared again to AFM using simple algebraic techniques and visual inspection. Finally, the models were examined to discern if there was a point at which the insights yielded by the model would change. The method for this analysis was to use regression techniques, including stepwise regression, to fit regression lines to the output from each model. These regression lines were then plotted to determine if any intersections existed, which would indicate points at which insights would change between models.

Additional Insights

This sensitivity analysis, as with other studies of its type, provide many opportunities to examine what effects changes in the input parameters or independent variables have on the dependent output response variable of interest. While earlier only

three basic independent variables were identified, in fact several other contributing factors possibly affecting the length of time required for cargo to move through a system vary with the change in origin-destination pair. In the course of regression analysis on each model, several of these factors were able to be introduced and inspected to determine their effects on the closure time. This led to a suggestion as to what factors may affect closure the most. This would be an important additional note to USTRANSCOM as it could allow them to focus on certain areas for improvement toward meeting the goal of deploying a Stryker Brigade in 4 days (or confirm their previous assessments of critical constraints to closure).

Summary

The methodology is the backbone of the experimental process. The methodology provides a road map for reaching the answers to the questions posed that from the basis of a study. The road map that is displayed in this methodology was used to guide the analysis conducted in support of this research and displayed in chapter four.

IV. Analysis and Results

Chapter Overview

This chapter summarizes the results of the statistical discoveries and mathematical comparisons between the outputs from the Quick Look Tool, Modified Quick Look Tool, and Arena, respectively, and the Airlift Flow Model. First discussed are the inputs and parameters dictated to each model, and the verification and validation techniques applied. Basic model output results are then displayed and simple statistical comparisons are discussed. Results of regression analysis are then displayed, and finally the additional insights revealed through this examination are discussed.

Inputs and Parameters

The key to ensuring a valid set of comparisons is to properly control the inputs and parameters over which each model is exercised. For this study, there were two basic dependent variables that were applied similarly to each model. In addition, there were ten different origin-destination pairs to which each set of independent variables were applied to test for deployment closure. However, each of the models also had several other adjustable factors that contributed to determining the final outcome results. These adjustable parameters were not treated exactly the same over each model; this contributes to some of the differences in outputs between models. What follows is a breakdown of all adjustable factors, including independent variables, and how they were set for each treatment and model.

Weight of total cargo to be moved. For this study, cargo movement requirements were held constant at 14,663 short tons.

Route. As mentioned before, each origin-destination pair was constrained to a single set of en route locations, consistent with those defined in Appendix C of the 2002 USTRANSCOM study. This information is available at appendix B to this study. Distance between en routes: the length of each flying leg was also defined in the 2002 study and is again available at Appendix B herein.

Parking spots and hot cargo pads (HCP). With Quick Look and Modified Quick Look, there was only one setting available for number of parking spots and HCP available at en route locations, regardless of the number of en routes required in a route. Therefore, the selector had to be set for the most constraining en route location in each origin-destination pair. Cargo could move through the entire system no faster than it could move through the tightest point. With Arena modeling each en route separately, each node had to be built to represent a specific number of parking spots and HCP. In order to properly model the constraints of HCP on total throughput, the number of effective parking spots under a certain percentage of aircraft requiring hot cargo spots was calculated. The formula is:

$$\textit{Effective MOG with (x)\% hot cargo} = \min\{\textit{total parking spots}, HCP/(x/100)\} \qquad (15)$$

Queuing efficiency factor. This was an adjustment factor available in Quick Look that was carried over to the modified Quick Look. The purpose of this factor was to attempt to capture some of the delays due to queuing for parking spots and resources at bases within the en route system. This parameter was thus not considered in the Arena model, as Arena already has as in its underlying code a queuing discipline defined. After

several experiments to replicate the reported outputs from Quick Look, it was determined that the required setting for this factor was 100%.

Validation

Validation is the process of assessing how well a model replicates the system it is supposed to represent (Carson, 2002: 1). That, in a form, is the entire thrust of this work - to compare the nominated models to the model held up as the gold standard, AFM. The goal of this study is not to pass judgment on whether certain models were the correct models to be used for evaluating the deployment of the Stryker Brigade -- rather, it is to examine ways in which the outputs of the nominated models differ. Because this is a case study comparison of modeling methods, and not an effort to fit the best model to a real situation, validation of the models to external systems is not applicable in this work. The models presented from previous works are assumed to be both verified and validated.

Verification

Verification involves exercising an "apparently correct model for the specific purpose of finding and fixing modeling errors" (Carson, 2002:1). Basically, the concern is that the model behaves the way it is expected to. In this case, an example would be that relaxing some of the input parameters that are constrains to closure and having the model reflect decreased closure times. Again, the only two models with which verification may be a concern in this study would be the set of Arena models and, to a lesser extent, the modified Quick Look Tool. Typical rigorous methods of verification were difficult in this instance, as the data points available for comparison are not great enough in number to allow for a set to be held back from the creation of each model for verification. Instead, for this study, a simple method of inspection was used for

verification. Representative origin - destination pairs were selected, and a series of parameter adjustments were made to ensure that the expected reactions from the models were witnessed. In order to avoid replicating runs that would be carried out in the course of the study comparisons, adjustments were made to the amount of cargo required to be moved, and separately, the cargo loads and ground times were fixed and then adjusted up or down. The expected reactions to parameter adjustments were witnessed. For example, when the amount of cargo was decreased, the time required to close went down, and when ground times were increased, the estimate of closure time increased. Also, the actual runs of the models used in the study comparisons served as an additional level of verification, as the results from each model reflected the expected changes in reaction to the adjustments in the independent variables.

Results of Simulation Scenarios

Both models created for this experiment were run to replicate the 30 treatments for which data was available from previous runs of QLT and AFM. Table 4.1 is a composite chart of the output data from the runs all four models examined. While the 1,000 trials run with both Arena and Modified QLT yielded a series of statistics including median, range, variance, and half-width for each treatment, only point estimates of mean closure times are displayed to facilitate comparisons. As discussed earlier, Quick Look and AFM results available were not reported with any data relating to a range or variance in closure estimates. Also included in this first table are the two independent variables for these trials, fleet and percent of deploying aircraft requiring hot cargo pads, as well as the factor of primary differentiation between origin-destination pairs, round trip distance. For points where AFM and QLT disagreed on round trip distance, distances calculated

from the routes outlined in the USTRANSCOM 2002 IBCT study, Appendix C, Aerial Routing (2002), are reported. All reported values are in units of days estimated for closure.

Table 2. Compiled Model Results

	origin-destination pair	total roundtrip distance	# C-17	# C-5	% sorties req HCP	AFM closure time (days)	Quick Look Tool closure time (days)	QLT modified mean	Arena Mean
base deployment case	Alexandria-Venezuela	4324	42	48	50%	5.6	5.2	6.44	5.460
	McChord-Columbia	6541	42	48	50%	6.5	5.3	6.54	6.56
	Hickam-New Guinea	9356	42	48	50%	8.2	6.9	9.77	9.51
	Wheeler Sack-Sierra Leone	10457	42	48	50%	15.1	13.1	18.71	18.10
	Ramstein-Congo	12709	42	48	50%	14	9.1	12.93	16.43
	McChord-Balkans	13109	42	48	50%	8.1	6.3	7.34	7.20
	Elmendorf-Sri Lanka	14978	42	48	50%	10.1	7.3	10.25	10.19
	Eielson-Sri Lanka	15224	42	48	50%	8.9	7.3	10.25	10.18
	Wheeler-Sack-Congo	16393	42	48	50%	19.1	13.5	19.20	19.19
	McChord-Angola	17171	42	48	50%	15.6	13.6	19.26	19.31
deployment case D	Alexandria-Venezuela	4324	84	60	25%	5.5	3.1	3.41	4.51
	McChord-Columbia	6541	84	60	25%	4.7	3.2	4.44	4.63
	Hickam-New Guinea	9356	84	60	25%	8.2	5.6	5.26	9.49
	Wheeler Sack-Sierra Leone	10457	84	60	25%	10.9	6.9	9.70	9.56
	Ramstein-Congo	12709	84	60	25%	14	7	9.85	15.70
	McChord-Balkans	13109	84	60	25%	7	4.3	5.10	4.97
	Elmendorf-Sri Lanka	14978	84	60	25%	7.3	5	5.89	6.42
	Eielson-Sri Lanka	15224	84	60	25%	6.9	5	5.89	6.23
	Wheeler-Sack-Congo	16393	84	60	25%	15.7	7.3	10.20	10.01
	McChord-Angola	17171	84	60	25%	13	7.4	10.24	10.40
deployment case I	Alexandria-Venezuela	4324	135	100	25%	5.3	3.1	3.41	4.52
	McChord-Columbia	6541	135	100	25%	4.6	3.2	4.44	4.624
	Hickam-New Guinea	9356	135	100	25%	8.2	5.6	5.26	9.43
	Wheeler Sack-Sierra Leone	10457	135	100	25%	10.7	6.9	9.71	9.53
	Ramstein-Congo	12709	135	100	25%	13.9	7	9.86	16.16
	McChord-Balkans	13109	135	100	25%	6.9	3.7	4.97	4.25
	Elmendorf-Sri Lanka	14978	135	100	25%	7.2	4.2	5.74	6.38
	Eielson-Sri Lanka	15224	135	100	25%	6.5	4.2	5.74	6.19
	Wheeler-Sack-Congo	16393	135	100	25%	15.2	7.3	10.20	9.99
	McChord-Angola	17171	135	100	25%	12.9	7.4	10.25	10.36

From inspection, it appears that the Quick Look Tool consistently returned optimistic estimates of closure, while the modified QLT and Arena models both returned results that fell either side of the AFM closure calculations. This is the first note that differing insights may result from using different models to simulate these treatments, and provides us with reason to further examine these sets of data.

Further detailed results from the runs of the Modified QLT model, including range and variance information, are displayed in Table 3. The half-width statistic reported is the expected 95% confidence interval about the mean based on the trials recorded. As the version of Quick Look that was made available for this study did not provide separate calculations for routes from originating from Elmendorf and Eielson, only nine sets of origin-destination pairs are displayed. Deterministically modeling routes originating from Eielson using Elmendorf as the origin should not affect the results of this study and comparisons, as the 2002 reported closure estimates using Quick Look are identical for the routes originating form these locations and using Sri Lanka as the APOD (Reckamp and others, 2002: 45-47).

The further detailed results from the runs of the Arena model are next displayed at Table 4. The Arena model was able to successfully model deployments from Eielson AFB and Elmendorf AFB separately, and thus separate outputs are included for each. Arena did not report median, standard deviation, and variance, thus they are not displayed here. As these statistics are not part of the primary comparisons in this study, the missing statistics do not affect the conclusions.

Table 3. Crystal Ball Modified Quick Look Tool Results

Base Case; 48 x C-5, 42 x C-17; 50% A/C req. HCP

Statistics	McChord AFB-Balkans	Ramstien - Congo	Elmendorf-Sri Lainka	McChord-Angola	McChord - South America
Trials	1000	1000	1000	1000	1000
Mean	7.34	12.93	10.25	19.26	6.54
Median	7.05	12.35	9.83	18.43	6.24
Standard Deviation	1.30	2.87	2.21	1.47	1.38
half-width	0.08	0.18	0.14	0.09	0.09
Variance	1.69	8.23	4.89	17.96	1.90
Range Minimum	5.44	8.60	6.96	12.81	4.48
Range Maximum	15.62	29.17	23.08	43.18	14.68
Range Width	10.18	20.57	16.13	30.38	10.21

	Alexandria - Venezuela	Wheeler-Sack - Congo	Hickam - New Guinea	Wheeler-Sack Sierra Leone
Trials	1000	1000	1000	1000
Mean	6.44	19.20	9.77	18.71
Median	6.13	18.38	9.35	17.89
Standard Deviation	1.40	4.22	2.16	4.17
half-width	0.09	0.26	0.13	0.26
Variance	1.96	17.81	4.65	17.42
Range Minimum	4.37	12.77	6.52	12.31
Range Maximum	14.87	42.98	22.15	41.95
Range Width	10.50	30.21	15.64	29.64

Case D; 60 x C-5, 84 x C-17; 25% A/C req. HCP

Statistics	McChord- Balkans	Ramstien - Congo	Elmendorf-Sri Lainka	McChord-Angola	McChord - Columbia
Trials	1000	1000	1000	1000	1000
Mean	5.10	9.85	5.89	10.24	4.44
Median	4.87	9.42	5.63	9.78	4.24
Standard Deviation	0.92	2.15	1.05	2.15	0.96
half-width	0.06	0.13	0.07	0.13	0.06
Variance	0.85	4.62	1.10	4.63	0.91
Range Minimum	3.74	6.57	4.35	6.95	2.99
Range Maximum	9.97	20.89	11.66	21.35	9.35
Range Width	6.23	14.32	7.31	14.40	6.36

	Alexandria - Venezuela	Wheeler-Sack - Congo	Hickam - New Guinea	Wheeler-Sack Sierra Leone
Trials	1000	1000	1000	1000
Mean	3.41	10.20	5.26	9.70
Median	3.25	9.74	5.02	9.27
Standard Deviation	0.70	2.14	1.10	2.11
half-width	0.04	0.13	0.07	0.13
Variance	0.49	4.59	1.22	4.45
Range Minimum	2.46	6.92	3.59	6.46
Range Maximum	7.12	21.31	10.87	20.72
Range Width	4.66	14.40	7.28	14.26

Case I; 100 x C-5, 135 x C-17; 25% A/c req. HCP

Statistics	McChord- Balkans	Ramstien - Congo	Elmendorf-Sri Lainka	McChord-Angola	McChord - Columbia
Trials	1000	1000	1000	1000	1000
Mean	4.97	9.86	5.74	10.25	4.44
Median	4.75	9.41	5.49	9.79	4.24
Standard Deviation	1.00	2.15	1.14	2.15	0.95
half-width	0.06	0.13	0.07	0.13	0.06
Variance	1.00	4.61	1.31	4.61	0.91
Range Minimum	3.47	6.58	4.03	6.96	2.99
Range Maximum	10.04	20.81	11.75	21.33	9.34
Range Width	6.57	14.23	7.72	14.37	6.35

	Alexandria - Venezuela	Wheeler-Sack - Congo	Hickam - New Guinea	Wheeler-Sack Sierra Leone
Trials	1000	1000	1000	1000
Mean	3.41	10.20	5.26	9.71
Median	3.25	9.73	5.02	9.27
Standard Deviation	0.70	2.14	1.10	2.11
half-width	0.04	0.13	0.07	0.13
Variance	0.49	4.58	1.21	4.44
Range Minimum	2.46	6.92	3.60	6.47
Range Maximum	7.09	21.29	10.86	20.70
Range Width	4.63	14.37	7.27	14.23

Table 4. Arena Model Results

Base Case; 48 x C-5, 42 x C-17; 50% A/C req. HCP

Statistics	McChord AFB-Balkans	Ramstien - Congo	Elmendorf-Sri Lainka	McChord-Angola	McChord - South America
Trials	1000	1000	1000	1000	1000
Mean	7.20	16.43	10.19	19.31	6.56
half-width	0.01	0.03	0.02	0.03	0.01
Range Minimum	6.77	15.13	9.40	17.96	6.07
Range Maximum	9.13	17.98	11.79	21.02	7.52
Range Width	2.36	2.84	2.38	3.06	1.44
	Alexandria - Venezuela	Wheeler-Sack - Congo	Hickam - New Guinea	Wheeler-Sack Sierra Leone	**Eielson - Sri Lanka**
Trials	1000	1000	1000	1000	1000
Mean	5.46	19.19	9.51	18.10	10.18
half-width	0.00	0.03	0.02	0.03	0.02
Range Minimum	5.28	17.85	8.78	16.50	9.48
Range Maximum	6.28	20.88	10.65	20.07	11.33
Range Width	1.00	3.03	1.87	3.57	1.85

Case D; 60 x C-5, 84 x C-17; 25% A/C req. HCP

Statistics	McChord- Balkans	Ramstien - Congo	Elmendorf-Sri Lainka	McChord-Angola	McChord - Columbia
Trials	1000	1000	1000	1000	1000
Mean	4.97	15.70	6.42	10.40	4.63
half-width	0.01	0.03	0.01	0.02	0.01
Range Minimum	4.63	14.54	5.96	9.62	4.26
Range Maximum	6.40	17.80	8.29	12.19	5.33
Range Width	1.77	3.26	2.33	2.56	1.07
	Alexandria - Venezuela	Wheeler-Sack - Congo	Hickam - New Guinea	Wheeler-Sack Sierra Leone	**Eielson - Sri Lanka**
Trials	1000	1000	1000	1000	1000
Mean	4.51	10.01	9.49	9.56	6.23
half-width	0.02	0.02	0.02	0.02	0.01
Range Minimum	4.13	9.24	8.84	8.85	5.74
Range Maximum	9.78	12.27	10.63	10.88	7.53
Range Width	5.64	3.03	1.80	2.03	1.79

Case I; 100 x C-5, 135 x C-17; 25% A/c req. HCP

Statistics	McChord- Balkans	Ramstien - Congo	Elmendorf-Sri Lainka	McChord-Angola	McChord - Columbia
Trials	1000	1000	1000	1000	1000
Mean	4.25	16.16	6.38	10.36	4.62
half-width	0.01	0.03	0.01	0.02	0.01
Range Minimum	3.93	15.11	5.96	9.75	4.27
Range Maximum	6.00	18.26	7.60	11.41	6.79
Range Width	2.07	3.15	1.64	1.66	2.52
	Alexandria - Venezuela	Wheeler-Sack - Congo	Hickam - New Guinea	Wheeler-Sack Sierra Leone	**Eielson - Sri Lanka**
Trials	1000	1000	1000	1000	1000
Mean	4.52	9.99	9.43	9.53	6.19
half-width	0.01	0.02	0.02	0.02	0.01
Range Minimum	4.15	9.30	8.73	8.88	5.80
Range Maximum	9.41	11.14	10.34	11.32	7.41
Range Width	5.25	1.84	1.61	2.44	1.61

Forecast Error Terms

A first method of inspecting the differences among the outputs of the several models, beyond a visual inspection of the raw data output, is to treat each model as a forecast of the predicted output expected from AFM to model the same treatments. Calculation of the difference between each predicted point and the AFM output, in this case treated as the "actual," form the error terms. The raw data errors from all model outputs in this study are displayed in Table 5. Admittedly, there are some difficulties in making comparisons between the several models due to the precision with which the Quick Look and AFM data are reported (only one decimal place) in the USTRANSCOM study (Reckamp and others, 2002: 45-47). The data available from the user-run simulations with Arena and Modified Quick Look were available to ten decimal places, but for the purposes of display, have been truncated to two. Additional precision is unnecessary as that would begin to involve calculations considering units of time in minutes or smaller, which would be of little consequence when judging the ability to meet a goal set in units of days. Furthermore, the differences in the error terms displayed at Table 6 are great enough that limiting the precision with which results are reported should not change the observations made about the change in insights when moving between models.

Simple error terms don't explain much beyond what can be gathered from a visual examination of the raw data output. However, several statistical measures of model error exist to provide us with a more concise picture of what has happened in our study. For this research work, four statistical error measures are initially considered, including mean error, mean absolute error, mean percent error, and mean absolute percent error.

Table 5. Error Data

		Δ from AFM			abs Δ from AFM			% Δ from AFM			abs % Δ from AFM		
	tmnt #	QLT	QLT Mod	Arena	QLT	QLT Mod	Arena	QLT	QLT Mod	Arena	QLT	QLT Mod	Arena
base deployment case	1	0.4	-0.84	0.14	0.4	0.84	0.14	7.1%	-15.02%	2.51%	7.1%	15.02%	2.51%
	2	1.2	-0.04	-0.06	1.2	0.04	0.06	18.5%	-0.61%	-0.90%	18.5%	0.61%	0.90%
	3	1.3	-1.57	-1.31	1.3	1.57	1.31	15.9%	-19.13%	-15.97%	15.9%	19.13%	15.97%
	4	2	-3.61	-3.00	2	3.61	3.00	13.2%	-23.89%	-19.88%	13.2%	23.89%	19.88%
	5	4.9	1.07	-2.43	4.9	1.07	2.43	35.0%	7.62%	-17.38%	35.0%	7.62%	17.38%
	6	1.8	0.76	0.90	1.8	0.76	0.90	22.2%	9.43%	11.05%	22.2%	9.43%	11.05%
	7	1.6	-1.35	-1.28	1.6	1.35	1.28	18.0%	-15.22%	-14.38%	18.0%	15.22%	14.38%
	8	2.8	-0.15	-0.09	2.8	0.15	0.09	27.7%	-1.53%	-0.85%	27.7%	1.53%	0.85%
	9	5.6	-0.10	-0.09	5.6	0.10	0.09	29.3%	-0.55%	-0.49%	29.3%	0.55%	0.49%
	10	2	-3.66	-3.71	2	3.66	3.71	12.8%	-23.45%	-23.81%	12.8%	23.45%	23.81%
deployment case D	11	2.4	2.09	0.99	2.4	2.09	0.99	43.6%	37.99%	18.07%	43.6%	37.99%	18.07%
	12	1.5	0.26	0.07	1.5	0.26	0.07	31.9%	5.55%	1.53%	31.9%	5.55%	1.53%
	13	2.6	2.94	-1.29	2.6	2.94	1.29	31.7%	35.87%	-15.77%	31.7%	35.87%	15.77%
	14	4	1.20	1.35	4	1.20	1.35	36.7%	10.97%	12.34%	36.7%	10.97%	12.34%
	15	7	4.15	-1.70	7	4.15	1.70	50.0%	29.63%	-12.11%	50.0%	29.63%	12.11%
	16	2.7	1.90	2.03	2.7	1.90	2.03	38.6%	27.20%	28.95%	38.6%	27.20%	28.95%
	17	1.9	1.01	0.67	1.9	1.01	0.67	27.5%	14.60%	9.75%	27.5%	14.60%	9.75%
	18	2.3	1.41	0.88	2.3	1.41	0.88	31.5%	19.28%	12.03%	31.5%	19.28%	12.03%
	19	8.4	5.50	5.69	8.4	5.50	5.69	53.5%	35.05%	36.22%	53.5%	35.05%	36.22%
	20	5.6	2.76	2.60	5.6	2.76	2.60	43.1%	21.21%	20.01%	43.1%	21.21%	20.01%
deployment case I	21	2.2	1.89	0.78	2.2	1.89	0.78	41.5%	35.64%	14.80%	41.5%	35.64%	14.80%
	22	1.4	0.16	-0.02	1.4	0.16	0.02	30.4%	3.43%	-0.52%	30.4%	3.43%	0.52%
	23	2.6	2.94	-1.23	2.6	2.94	1.23	31.7%	35.83%	-15.03%	31.7%	35.83%	15.03%
	24	3.8	0.99	1.17	3.8	0.99	1.17	35.5%	9.24%	10.95%	35.5%	9.24%	10.95%
	25	6.9	4.04	-2.26	6.9	4.04	2.26	49.6%	29.08%	-16.24%	49.6%	29.08%	16.24%
	26	3.2	1.93	2.65	3.2	1.93	2.65	46.4%	27.94%	38.46%	46.4%	27.94%	38.46%
	27	2.3	0.76	0.31	2.3	0.76	0.31	35.4%	11.66%	4.71%	35.4%	11.66%	4.71%
	28	3	1.46	0.82	3	1.46	0.82	41.7%	20.25%	11.37%	41.7%	20.25%	11.37%
	29	7.9	5.00	5.21	7.9	5.00	5.21	52.0%	32.87%	34.28%	52.0%	32.87%	34.28%
	30	5.5	2.65	2.54	5.5	2.65	2.54	42.6%	20.54%	19.66%	42.6%	20.54%	19.66%

Mean error is the simplest of error measures, but typically provides little information and is usually relatively small as the positive errors tend to be offset by negative errors, and thus does not give much information relative to the size of the typical error made by the predictor. However, a large mean error can serve to highlight a forecast bias of consistent over- or under- estimating in the forecasts (Makridakis and others, 1998: 43). In the course of this study, an overestimate would be considered a conservative estimate of the ability to meet closure, while an underestimate would be considered an optimistic estimate of the ability to meet closure. The formula for mean error, adapted for this study, is:

$$Mean\ Error\ =\ \sum_{i=1}^{n}\frac{(AFM_i - Model_i)}{n} \qquad (16)$$

Mean absolute error, which first converts each error term to be non-negative before summing and averaging the results, is not affected by these cancellation effects. Thus, it has the advantage of showcasing the real mean distance by which the forecast missed the actual (Makridakis and others, 1998: 43). The formula for mean absolute error is:

$$Mean\ Absolute\ Error\ =\ \sum_{i=1}^{n} \frac{\left| AFM_i \text{ - } Model_i \right|}{n} \tag{17}$$

Neither mean error nor mean absolute error, however, take into account the scale of the data being measured. As a result, comparisons across different time series or of events having a significantly different range of results are not fully supported by these terms. To account for scale in comparison, percent error is a helpful tool. Mean percent error, similar to mean error, allows for positive and negative error terms to cancel each other out, but still be helpful in identifying any optimistic (for the purposes of this study, low-sided or positive) or conservative (negative, or high-sided) bias (Makridakis and others, 1998: 43-44) . The formula for mean percent error is:

$$Mean\ Percent\ Error\ =\ \frac{1}{n} \sum_{i=1}^{n} \frac{(AFM_i \text{ - } Model_i)}{AFM_i} \tag{18}$$

Mean Absolute percent error has the same advantages that are inherent in the mean absolute error, as well as the adjustment for scale prevalent in the mean percent error. The only drawbacks to using mean absolute percent error for comparisons are when a meaningful origin is not present, i.e. when the zero on the scale is arbitrary, or when in time series values at or very close to zero are common (Makridakis and others,

1998: 44). Neither of these are the case in this study. The formula for mean absolute percent error is:

$$Mean\ Absolute\ Percent\ Error \ = \ \frac{1}{n}\sum_{i=1}^{n}\frac{\left|AFM_i \text{ - } Model_i\right|}{AFM_i} \tag{19}$$

Table 4.5 displays the computed error terms for each model judged in its ability to predict the closure estimates from AFM. These terms give a first look assessment of the ability of each model to predict the closure estimates produced by AFM. These results provide interesting analysis as to the level of fidelity with which Mean error and mean absolute error terms are reported in days. The first observation from this table is confirmation of the initial suspicion that Quick Look is consistently optimistic, underestimating the closure time compared with AFM. This is confirmed through the relatively high mean error and the fact that the mean error and the mean absolute error are identical, indicating a lack of negative deviations (points where actual - forecast < 0) to cancel out any of the positive deviations.

Table 6. Error Terms Gathered

model	Quick Look	Modified Quick Look	Arena
mean error	3.36	1.18	0.34
mean abs error	3.36	1.94	1.58
mean % e	33.16%	12.72%	4.44%
mean abs % e	33.16%	19.34%	14.67%

Means comparisons

An important statistic regularly reported and gauged in the original USTRANSCOM IBCT study was the mean closure time for all origin-destination pairs considered for a particular case of deployment parameters (Reckamp and others, 2002). In that vein, another meaningful measure of the differences or possible changes in insights gained from using differing models is to compare the different mean closure times from each model over each case. What would be of particular interest in this case would be if we were to observe an instance where one model may suggest that over a certain set of parameters, a set deployment closure time goal my be achievable, whereas other models disagree.

Several insights into the similarities and differences between model insights are evident in the chart at Table 7. Evidence suggests that each model shows significant improvement in closure time from the base case to case D, but very little improvement from case D to case I. However, this is where the similarities seem to end. One simple observation from this table further confirms that Quick Look is consistently the most optimistic model for estimating closure. An interesting observation from this table is that while Arena and the modified Quick Look are both more conservative than AFM in the base case, they are both more conservative in other cases, yet still not as optimistic in their estimates as the basic Quick Look. This observation provides basis for continuing the investigation to the differences in insights provided by the models.

Table 7. Mean Closure Times by Model and Case

	AFM	Quick Look	Quick Look mod	Arena
base	11.12	8.76	12.07	12.21
case D	9.32	5.48	7.00	8.19
case I	9.14	5.26	6.96	8.14

Another important drive from the USTRANSCOM study was to evaluate the improvements gained by adjusting some of the factors treated as independent variables. In that light, a key indicator of whether the insights provided by the models differ is the amount of improvement they reflect when constraints are relaxed. Table 8, an extension of Table 7, displays the improvements, measured in both days and percentage, for each model as the constraints (independent variables) are relaxed from the base case through case D and then case I. As displayed at Table 8, Arena and AFM, the discrete-event simulations, reveal smaller improvements, measured in both days improvement and percentage improvement, when measured over case D. However, when case I is applied, it is the two models which are employing similar distributions from which to draw aircraft loads and en route ground times that share the smallest improvements.

Table 8. Mean Improvements by Case and Model

	AFM		Quick Look		Quick Look mod		Arena	
Case D	1.8	15.55%	3.28	35.55%	5.07	40.66%	4.02	29.95%
Case I	0.18	2.09%	0.22	4.60%	0.04	0.71%	0.05	1.42%

As mentioned above, also worth investigating is how these insights into the ability to meet closure time may change if, as suggested in some other studies of Stryker Brigade deployments (Bower and others, 2003; GAO, 2003), the deployment closure goal was relaxed. Table 9 lists the number of origin-destination pairs (out of ten) for which a certain model estimates over a given case that the deployment closure goal can be achieved. It is interesting to note that in this comparison of models, the excel-based spreadsheets and the discrete-event simulation models continue to show similar changes when the closure goal is relaxed. Also, this table further highlights the optimistic nature of Quick Look.

Table 9. Estimates to Meet Closure Goals

	AFM			Quick Look			Quick Look modified			Arena		
	4 days	6 days	8 days	4 days	6 days	8 days	4 days	6 days	8 days	4 days	6 days	8 days
base case	0	1	2	0	2	6	0	0	3	0	1	3
case D	0	2	5	2	6	10	1	6	6	0	3	5
case I	0	2	5	3	6	10	1	6	6	0	3	5

Regression Results

Another method of evaluating the level of fidelity with which each model matches the outcomes produced by AFM is by plotting the expected values of closure gathered from AFM by the predicted estimates of days required for closure estimated by the several models. Included at Appendix D is a series of plots of AFM actual closure estimates against the closure estimates predicted by each model. What would be expected for each model would be to see a nearly linear pattern of plotted points along an axis lying 45 degrees from the origin, indicating that the model reasonably replicates the output from AFM.

What is evident in the plots is that there is a similar but increasing level of correlation throughout this set of three models when compared with AFM. Also of note is that the regression lines fit to each set of plots are associated with a slightly increasing R-Square value as the models increase in variability from Quick Look through to Arena. All models show and adjusted R-square value in the range of .73 to .80, and correlations between .86 and .89. These values work to hint that while there is a significant level of correlation across all models, there is still a significant amount of variance within the AFM model results that cannot be explained by the other three models. An interesting point to note are that all the points in the graph plotting AFM against Quick Look lie above a diagonal line running at a 45-degree angle from the origin, again indicating the severe forecast bias in the Quick Look model. Also of note is that each model shows improvement in the form of an increased adjusted R-square value by fitting a curve as opposed to a line through the data, indicating that the relationships between the models are not strictly linear.

Additional Insights

Through the methods of stepwise regression used to create meta-model equations for each model, the primary factors affecting closure time were revealed, as well as the total percent of variance that can be explained by each set of factors. While interesting in its own right, these additional insights generally were not different from what was discovered using the "constraints" evaluations included in the Quick Look Tool and reported and discussed at length in the USTRANSCOM IBCT study (Mahan and others, 2004; Reckamp and others, 2002). It was interesting to note that the number of en route stops and the percent of aircraft requiring use of hot cargo parking were the two factors

consistently reported across all models to contribute the most to determining the amount of time required for closure. Total roundtrip distance was also a factor reported in half of the models, but the total number of aircraft used to move the cargo was not sufficiently significant in any of the model estimates.

The figures found in Appendix E represent the resultant models created as meta-models from the four models in the study, beginning with AFM. Of note in these models is that the chosen predictors used to estimate the output of each model vary widely in their ability to match the outputs of the model itself, as borne out in the wide range of adjusted R-Square values, ranging from .45 for Arena to .95 for modified Quick Look. This makes it difficult to create a meaningful set of transformation functions among the models, and also indicates that some models must be affected differently by each parameter.

The resultant equations of the respective meta-models estimated through regression are:

$$\textit{AFM closure time} = .3132 - .0004 \times \textit{round trip distance} + 7.5600 \times x\textit{\%hot cargo} + 3.2422 \times \textit{\#en route stops} + .5951(\textit{\#en route stops} - 3.7)^2 + 6.6 \times 10^{-8}(\textit{round trip distance} - 12026.2)^2 \qquad (20)$$

$$\textit{Quick Look closure time} = -2.6699 + 13.5600 \times \textit{\%hot cargo} + 1.2567 \times \textit{\#en route stops} + 4.4149(\textit{\%hot cargo} - .333)(\textit{\#en route stops} - 3.7) \qquad (21)$$

$$\textit{Modified Quick Look closure time} = 1.1096 + .0002 \times \textit{round trip distance} + 12.3560 \times \%\textit{hot cargo} - .1473 \times \#\textit{en route stops} + .00025(\textit{round trip distance} - 12026.2)(\%\ \textit{hot cargo} - .333) + 1.75 \times 10^{-8}\ (\textit{round trip distance} - 12026.2)^2 \quad (22)$$

$$\textit{Arena closure time} = -2.514 + 16.1812x\%\textit{hot cargo} + 1.7935 \times \#\textit{en route stops} + 8.3453(\%\textit{hot cargo} - .333)(\#\textit{en route stops} - 3.7) \quad (23)$$

Summary

This chapter provided an exploration of the methods used in comparing the outputs of the models investigated in this study. The primary insights that were noted were that different models reflected different gains from relaxing constraints toward meeting closure, and that the Quick Look model was consistently biased low in its estimation. However, as shown through the regression analysis, simple equations can be applied to each model equating the model to AFM and serve to reduce much of the difference between the models.

V. Conclusions and Recommendations

Chapter Overview

As presented previously, the purpose of this research effort was to investigate differences between deployment simulation models and explore the varying insights each model may produce. Conclusions from previous chapters are presented in this chapter, as well as explanations of the significance of the research and recommendations for further study.

Conclusions of Research

Because of the relatively few data points available for comparison in this study, any conclusions drawn from this work are speculative at best. All conclusions suggested herein are reflections of what is indicated through the examination of the treatments available, and beg further study to continue the investigation into these relationships.

The collection of charts and graphs from chapter four suggests potential conclusions to this research. The first suggested conclusion, supported by the analysis of error terms in Table 6, is that adding variability into a deployment model, at either fleet or entity level, increases the fidelity of the model and its ability to closely replicate what is accepted as the real system. Adding variability is shown in this instance to reduce both forecast bias and shrink the average distance between the forecast estimate and the actual closure time result. Both of these measures indicate a more accurate forecast, and both improvement measures are apparent even when added at the macro (fleet) level within a spreadsheet model.

Further, the regression analysis combined with the analysis of error terms serves to suggest that even simple discrete-event models relying on queuing discipline rather

than algebraic analysis provide measurable gains in prediction reliability. Forecast closures estimated by these models are more accurate, less biased, and are more closely correlated to the accepted actual. As shown in Table 9, the queuing model also most likely to lead one to make the correct assessments as to the ability to meet a closure goal. In addition, these models provide information about the expected range and variance about the estimated mean closure times, and this information can provide additional opportunities for evaluation of ability to close.

Another conclusion of this study is that the application in models of newly identified ground time distributions reveals a greater sensitivity to the constraints of MOG, and particularly hot cargo parking spots, than previously thought. The appearance of this fact is suggested in Tables 7 and 8. Both the modified Quick Look and Arena, the models employing the new ground time distributions, show greater reductions in closure time when the percentage of aircraft requiring hot cargo parking spots is halved from the base case to case D than do AFM and Quick Look. AFM and Quick Look, conversely, show greater reductions in ground time between case D and case I, when the only change in treatments was increasing the number of aircraft.

An additional conclusion to this research is that, in conjunction with applications of regression analysis, use of deterministic models can nearly as accurately as queuing models predict outcomes. While this may seem at first to be in contradiction to my first conclusion above, it is important to note that this statement is qualified. Where we see comparable results from Quick Look and Arena are in their ability to, with the help of regression, explain over 80% of the variance in the AFM outputs. Even though Arena by

itself does a better job of predicting AFM, the regression equations relating Quick Look and Arena to AFM produce similarly close approximations of AFM outputs.

Significance of Research

The significance of this research is two-fold. First, it provides some suggestions to deployment planners about the methods that might be best in order to assess potential deployment actions. It also suggests that using the new en route ground time distributions in planning may provide more efficacy. Both points will be discussed in recommendations for action.

Recommendations for Action

The first suggestion for action is to continue using deterministic spreadsheet models as the baseline from which to begin situational sensitivity analysis. This use of spreadsheets as a predicting tool can be greatly enhanced if a set of results from a very robust model are known, and regression can be applied to equate the output of the two. Then, spread sheet models can be used to quickly and more accurately estimate the results realized from running the robust model. Also, if the spreadsheet models are shown to be still optimistically biased in their estimation, they can be used as an estimation of a floor to say that, since this most optimistic estimation does not conclude an action to be feasible, then it would be safe to assume that the more robust model would reach the same conclusion.

This would also suggest that additional work be done to investigate and identify distributions applicable to deployment planning factors. The work here has suggested that application of one planning factor distribution in particular can affect the conclusions drawn from estimating the ability to move cargo through a system; surely, if other

planning factors were investigated and found to be governed by significant distributions, use of these distributions in estimating aircraft movements would affect the outcome estimations further.

Finally, this research would recommend further tailoring of the set of Arena models used for this study. Arena is a useful and powerful tool and provides many additional capabilities compared with spreadsheet models while being simpler than AFM and other robust models. However, while the proprietary models built and used in this study were useful for analysis in this case, several areas for improvements in the models were identified which could aid in their continued use assessing the ability to move cargo. Primarily, an ability to consolidate the several models into one model using drop-down input cells would aid in the ability to model multiple routes with one model by allowing changes to routes, distances between airfields, parking spots, HCP, number en routes required without breaking down and re-building model.

Recommendations for Future Research

The power of the conclusions drawn is relatively weak as there are very few treatments over which to observe the several relationships. Suggestions for further study fall into three categories: making similar checks and tests using current fielded models, adding treatments across which the models are tested, and adding additional levels of variability into modified spreadsheet model.

This study used data from and exercised modified models originally developed in 2002. They were judges against a similarly dated set of data from another model run in 2002. AFM is no longer the standard, as newer models have been developed and implemented in its place. In order to increase the validity an applicability of the

comparisons between spreadsheet and discrete-event simulation models, the most current models should be analyzed for comparison.

Without the ability to compare models over the entire range and combination set of factors, it is impossible to make air-tight assessments of the relationships observed between the models. The reality could be that the relationships observed were only evident in the specially observed cases and do not carry forth to other treatments, or there may be significant relationships that are not discovered when examining only the treatments in this study. In order to be more assured of the findings presented in this study, similar comparisons should be made over a wider range of treatments to rule out coincidental observations.

The fact that only two inputs, cargo load and en route ground time, were allowed to vary in these studies also leaves room for further examination, particularly within the Quick Look model. It would be worth investigating the effects from adding additional levels of probability to other factors in the equation two factors nominated are on-load and off-load times. While it may be that adding additional levels of variability increase the fidelity of the spreadsheet model with respect to a baseline, gold-standard robust discrete-event simulator, it may also be the case that adding fleet-level random draws adds the possibility that several draws near the tail end of distributions are drawn during the same run and thus produce an outlying result.

Summary

This research provided as many questions as it did answers. It did, however, point out a few interesting discoveries. Elements of probability can be added to deterministic spreadsheet models and have an effect to increase the fidelity of the model.

Also, several methods of modeling used in conjunction can produce useful outputs and thus save the time and effort of repeatedly running detailed simulation models. In the end, the type of model necessary for analysis should be determined by the details required in the insights to be produced by the analyst.

Appendix A: Glossary of Acronyms

AMC Air Mobility Command

AFM Airlift Flow Model

AFPAM Air Force Pamphlet

APOD Aerial Port of Debarkation

APOE Aerial Port of Embarkation

EERISC European Enroute Infrastructure Steering Committee

GWOT Global War on Terror

HCP Hot Cargo Pad/Parking spot

IBCT Interim Brigade Combat Team

JIWG Joint Infrastructure Working Group

MOG Maximum (aircraft) on Ground

QLT Quick Look Tool

RTFT Round Trip Flying Time

TGT Total Ground Time

TPFDD Time-Phased Force Deployment Data

USTRANSCOM United States Transportation Command

Appendix B: En Route Capabilities/Aerial Routing

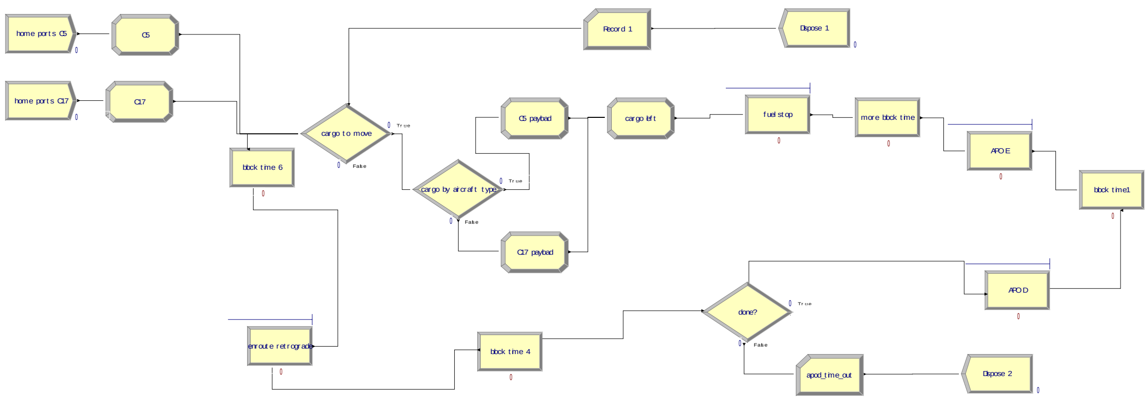
Scenario	Airfield	ICAO	Type of Stop	Distance	Fueling	Non-Hot Cargo Spots	Hot Cargo Spots	Effective MOG with 50% hot cargo
Wheeler-Sack AAF to Congo	Dover	KDOV	Fuel	-	X	9 or 9	3 or 3	6 or 6
	Wheeler-Sack AAF	KGTB	Onload	269		9 or 9	3 or 3	6 or 6
	Lajes	LPLA	En Route	2,180	X	8 or 8	1 or 1	2 or 2
	Ascencion	FHAW	En Route	2,894	X	8 or 8	1 or 1	2 or 2
	Lubumbashi	FZQA	Off	2,488		0	7 or 7	7 or 7
	Waterkloof	YMWK	Recover	856	X	9 or 9	na	9 or 9
	Ascencion	FHAW	En Route	2,656	X	8 or 8	1 or 1	7 or 7
	Roosevelt Roads	LPLA	En Route	3,419	X	9 or 9	na	9 or 9
	Dover	KDOV	Home	1,631	X	9 or 9	3 or 3	6 or 6
	Roundtrip Distance:			**16,393**				
McChord AFB to Angola	McChord	KTCM	Onload/Fuel	-	X	9 or 9	3 or 3	6 or 6
	Dover	KDOV	En Route	2,082	X	6 or 6	3 or 3	6 or 6
	Lajes	LPLA	En Route	2,231	X	8 or 8	1 or 1	2 or 2
	Ascension	FHAW	En Route	2,894	X	8 or 8	1 or 1	2 or 2
	Luanda	KNLU	Offload	1,641		0	7 or 7	7 or 7
	Ascension	FHAW	Recover	1,641	X	8 or 8	1 or 1	7 or 7
	Roosevelt Roads	TJNR	En Route	3,419	X	9 or 9	na	9 or 9
	McChord	KTCM	Home	3,263	X	9 or 9	3 or 3	6 or 6
	Roundtrip Distance:			**17,171**				
Wheeler-Sack AAF to Sierra Leone	Dover	KDOV	Fuel	-	X	6 or 6	3 or 3	6 or 6
	Wheeler-Sack AAF	KGTB	Onload	269		9 or 9	3 or 3	6 or 6
	Lajes	LPLA	En Route	2,180	X	8 or 8	1 or 1	2 or 2
	Freetown	GFLL	Offload	1,959		0	7 or 7	7 or 7
	Ascencion	FHAW	Recovery	999	X	9 or 9	na	9 or 9
	Roosevelt Roads	TJNR	En Route	3,419	X	9 or 9	na	9 or 9
	Dover	KDOV	Home	1,631	X	6 or 6	3 or 3	6 or 6
	Roundtrip Distance:			**10,457**				
Hickam AFB to New Guinea	Hickam	PHIK	Onload/Fuel	-	X	9 or 9	3 or 3	6 or 6
	Andersen	PGUA	En Route	3,289	X	7 or 7	2 or 2	4 or 4
	Port Moresby	AYPY	Offload	1,389		0	7 or 7	7 or 7
	Andersen	PGUA	Recover	1,389	X	7 or 7	2 or 2	4 or 4
	Hickam	PHIK	Home	3,289	X	9 or 9	3 or 3	6 or 6
	Roundtrip Distance:			**9,356**				
Alexandria IAP to Venezuela	Barksdale	KBAD	Fuel	-	X	9 or 9	na	9 or 9
	Alexandria IAP	KAEX	Onload	91	X	9 or 9	3 or 3	6 or 6
	Caracas	SVFM	Offload	2,026		0	7 or 7	7 or 7
	Roosevelt Roads	TJNR	Recover	471	X	9 or 9	na	9 or 9
	Barksdale	KBAD	Home	1,736	X	9 or 9	na	9 or 9
	Roundtrip Distance:			**4,324**				
McChord AFB to Colombia	McChord	KTCM	Onload/Fuel	-	X	9 or 9	3 or 3	6 or 6
	Kelly	KSKF	En Route	1,539	X	6 or 6	3 or 3	6 or 6
	Ernesto Cortissoz	SKBQ	Offload	1,734		0	7 or 7	7 or 7
	Randolph	KRND	Recover	1,726	X	9 or 9	na	9 or 9
	McChord	KTCM	Home	1,542	X	9 or 9	3 or 3	6 or 6
	Roundtrip Distance:			**6,541**				
Eielson AFB to Sri Lanka	Eielson	PAEI	Onload/Fuel	-	X	8 or 8	4 or 2	8 or 4
	Yokota*	RJTY	En Route	3,201	X	7 or 7	2 or 2	4 or 4
	U Taphao*	VTBU	En Route	3,194	X	7 or 7	2 or 2	4 or 4
	Colombo	VCBI	Offload	1,292		0	7 or 7	7 or 7
	Singapore	WSSS	Recover	1,484	X	9 or 9	na	9 or 9
	Kadena	RODN	En Route	2,034	X	9 or 9	na	9 or 9
	Eielson	PAEI	Home	4,019	X	8 or 8	4 or 2	8 or 4
	Roundtrip Distance:			**15,224**				

Scenario	Airfield	ICAO	Type of Stop	Distance	Fueling	Non-Hot Cargo Spots	Hot Cargo Spots	Effective MOG with 50% hot cargo
Elmendorf AFB to Sri Lanka	Elmendorf	PAED	Onload/Fuel	-	X	9 or 9	3 or 3	6 or 6
	Yokota*	RJTY	En Route	3,080	X	7 or 7	2 or 2	4 or 4
	U Taphao*	VTBU	En Route	3,194	X	7 or 7	2 or 2	4 or 4
	Colombo	VCBI	Offload	1,292		0	7 or 7	7 or 7
	Singapore	WSSS	Recover	1,484	X	9 or 9	na	9 or 9
	Kansai	RJBB	En Route	2,647	X	9 or 9	na	9 or 9
	Elmendorf	PAED	Home	3,281	X	9 or 9	3 or 3	6 or 6
			Roundtrip Distance:	**14,978**				
Ramstein AB to Congo	Ramstein	ETAR	Onload/Fuel	-	X	6 or 6	3 or 3	6 or 6
	Cario	HECW	En Route	1,815	X	2 or 1	2 or 1	4 or 2
	Nairobi	HKRE	En Route	3,071	X	2 or 2	2 or 2	4 or 4
	Lubumbashi	FZQA	Offload	832		0	7 or 7	7 or 7
	Ascension	FHAW	Recover	2,488	X	9 or 9	na	9 or 9
	Lajes	LPLA	En Route	2,894	X	9 or 9	na	9 or 9
	Ramstein	ETAR	Home	1,609	X	6 or 6	3 ro 3	6 or 6
			Roundtrip Distance:	**12,709**				
McChord AFB to Balkans	McChord	KTCM	Onload/Fuel	-		9 or 9	3 or 3	6 or 6
	McGuire	KWRI	Enroute	2,092	X	9 or 9	3 or 3	6 or 6
	Ramstein*	ETAR	Enroute	3,375	X	6 or 6	3 or 3	6 or 6
	Skopje	LYSK	Offload	1,033		0	7 or 7	7 or 7
	Rota	LERT	Recover	1,331	X	9 or 9	na	9 or 9
	Dover	KDOV	Enroute	3,196	X	9 or 9	na	9 or 9
	McChord	KTCM	Home	2,082	X	9 or 9	3 or 3	6 or 6
			Roundtrip Distance:	**13,109**				

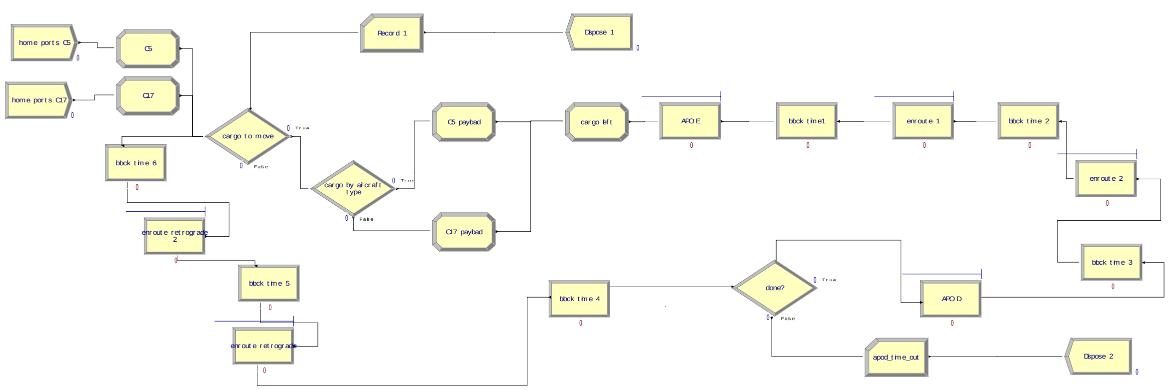
(Reckamp and others, 2004: 42-3)

Appendix C: Arena Model Graphical Representations

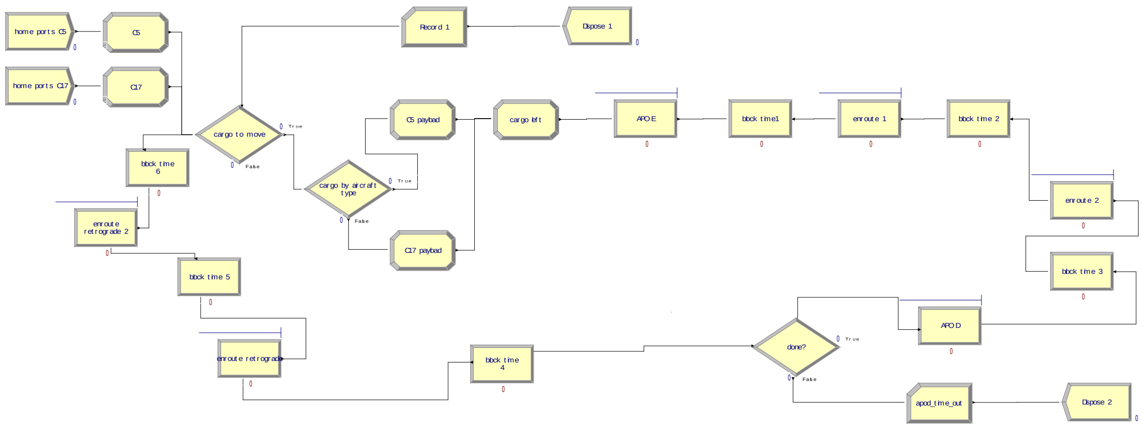
Alexandria - Venezuela model



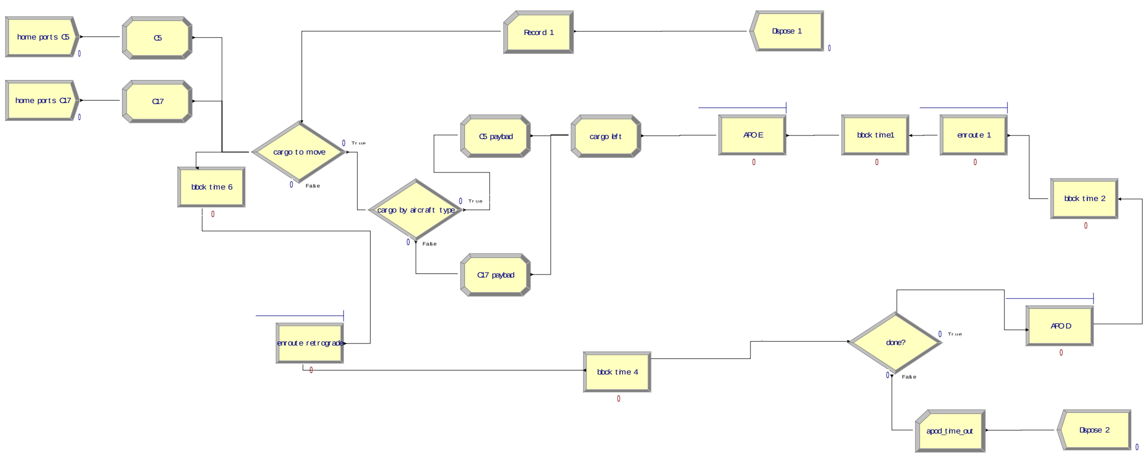
Eielson - Sri Lanka model



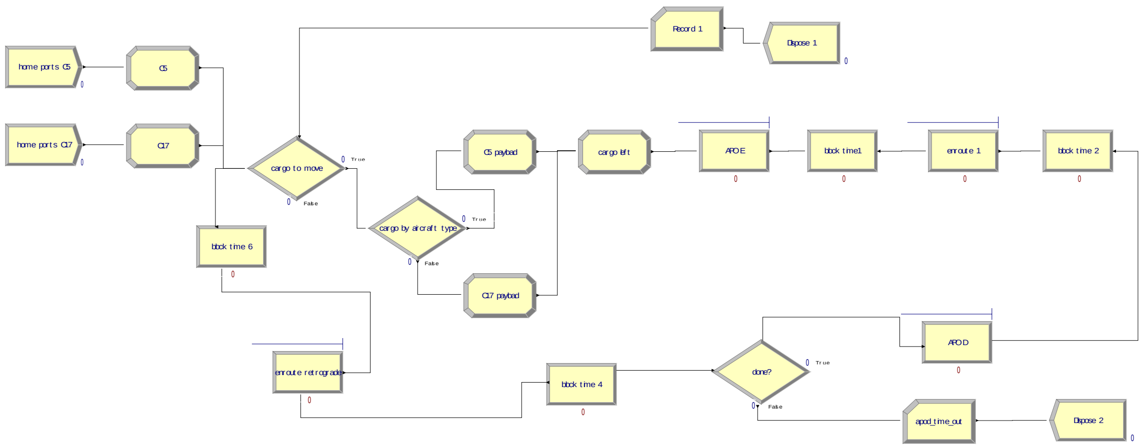
Elmendorf - Sri Lanka model



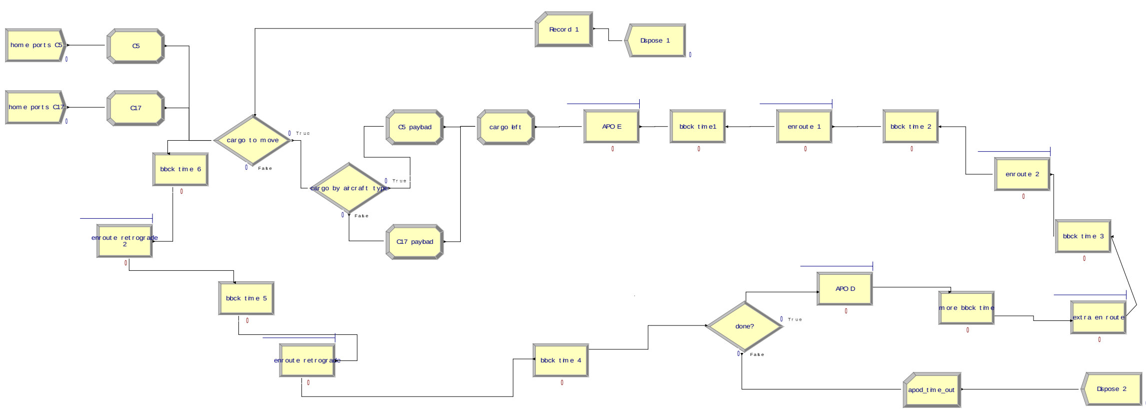
Hickam - New Guinea model



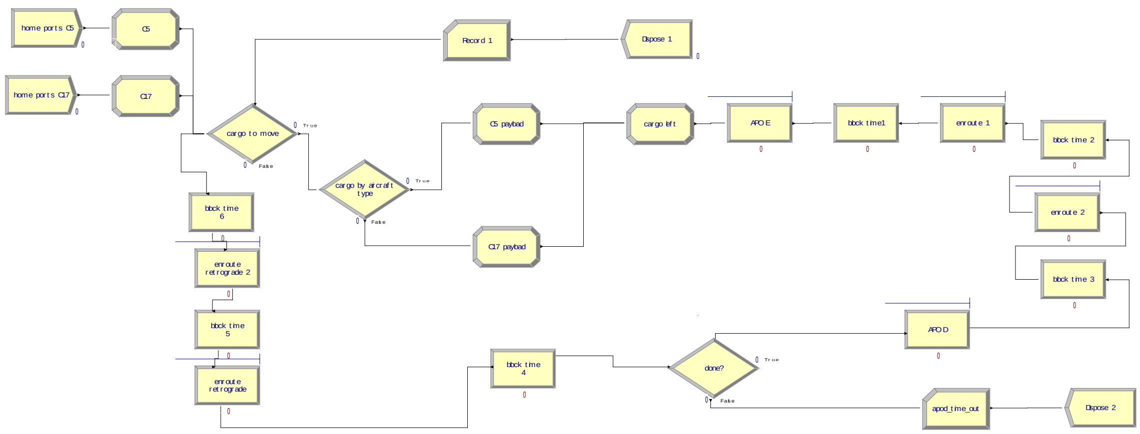
McChord - Columbia model



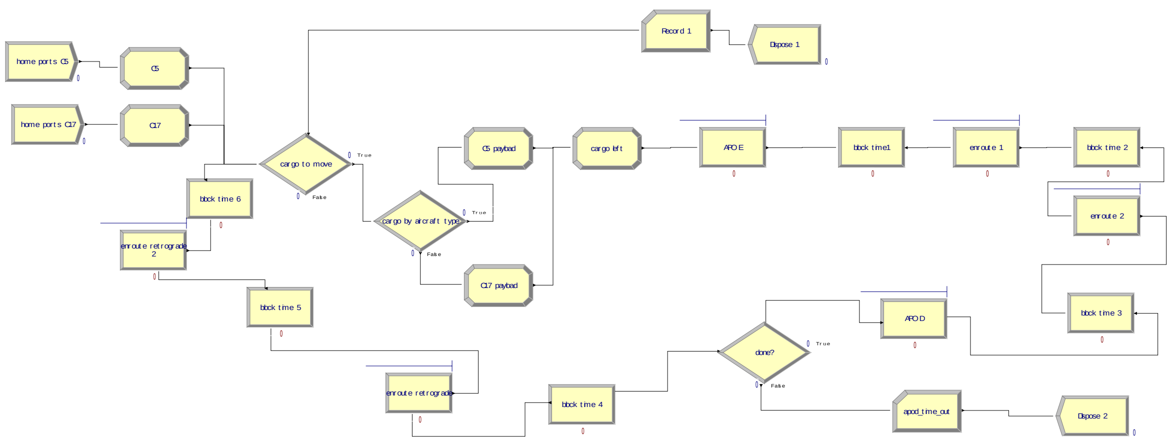
McChord- Angola model



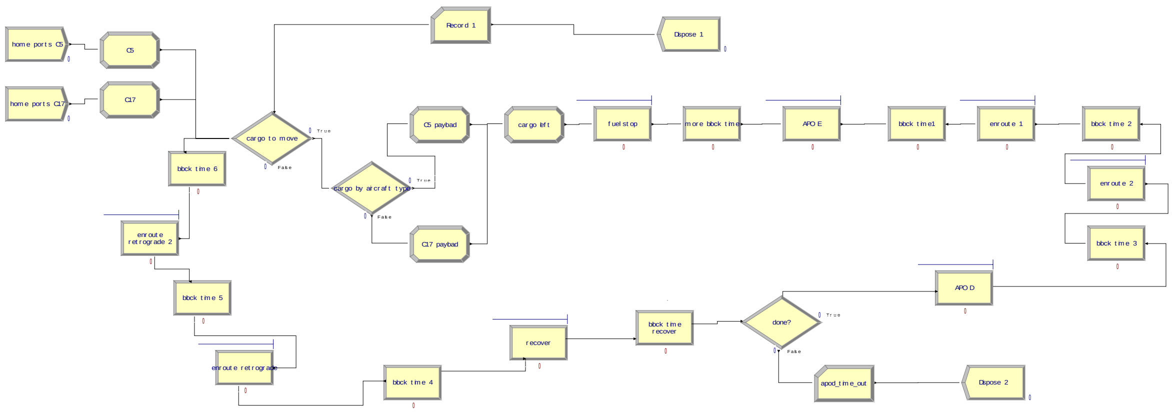
McChord - Balkans model



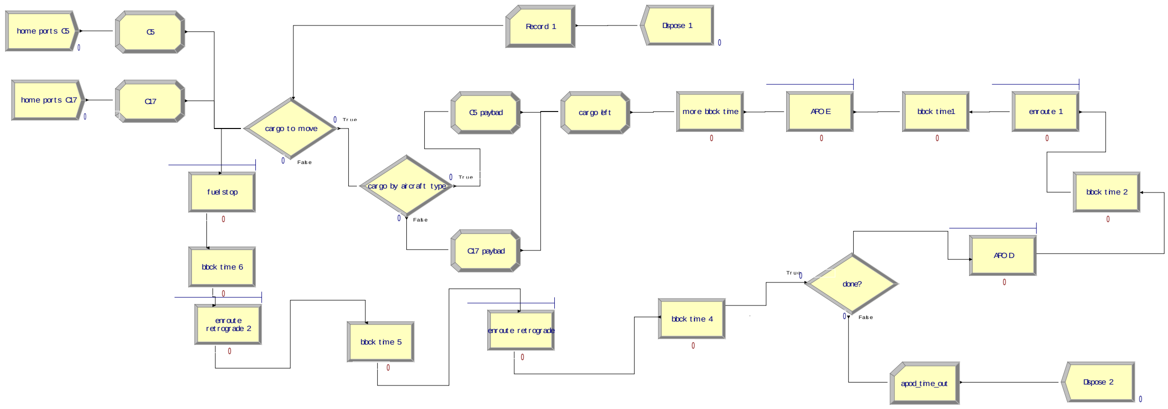
Ramstein - Congo model



Wheeler-Sack - Congo model



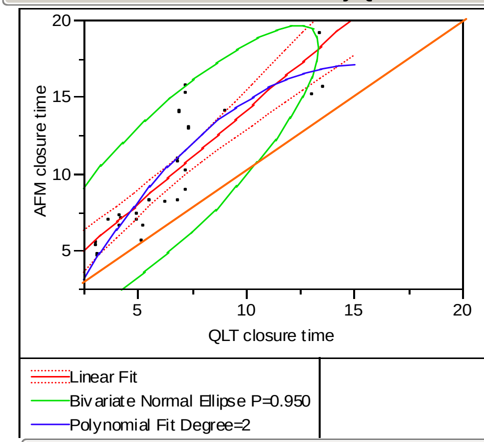
Wheeler-Sack - Sierra Leone model



Appendix D: JMP Regression Outputs

Plot of AFM by Quick Look Tool predicted values

Bivariate Fit of AFM closure time By QLT closure time



Linear Fit

AFM closure time = 1.9365688 + 1.2189894 QLT closure time

Summary of Fit

RSquare	0.74024
RSquare Adj	0.730963
Root Mean Square Error	2.080091
Mean of Response	9.86
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	345.24218	345.242	79.7920
Error	28	121.14982	4.327	Prob > F
C. Total	29	466.39200		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.9365688	0.9649	2.01	0.0545
QLT closure time	1.2189894	0.136465	8.93	<.0001

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
QLT closure time	6.5	2.830499	0.860372	0.0000	30
AFM closure time	9.86	4.010297			

Polynomial Fit Degree=2

AFM closure time = 0.6977909 + 1.512305 QLT closure time - 0.0862237 (QLT closure time-6.5)^2

Summary of Fit

RSquare	0.789051
RSquare Adj	0.773426
Root Mean Square Error	1.908894
Mean of Response	9.86
Observations (or Sum Wgts)	30

Analysis of Variance

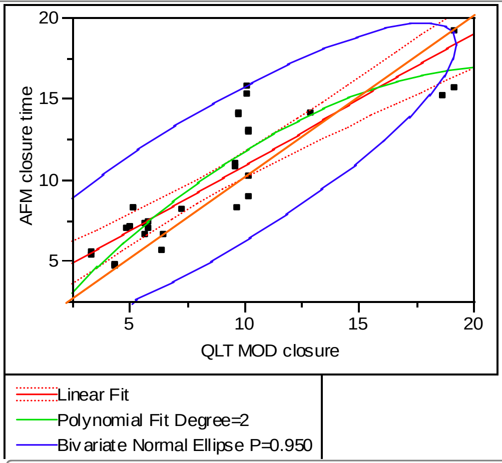
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	368.00730	184.004	50.4967
Error	27	98.38470	3.644	Prob > F
C. Total	29	466.39200		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.6977909	1.014749	0.69	0.4975
QLT closure time	1.512305	0.171623	8.81	<.0001
(QLT closure time-6.5)^2	-0.086224	0.034496	-2.50	0.0188

Plot of AFM by Modified Quick Look Tool predicted values

Bivariate Fit of AFM closure time By QLT MOD closure



Linear Fit

AFM closure time = 2.8992494 + 0.802392 QLT MOD closure

Summary of Fit

RSquare	0.755787
RSquare Adj	0.747066
Root Mean Square Error	2.016882
Mean of Response	9.86
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	352.49321	352.493	86.6542
Error	28	113.89879	4.068	Prob > F
C. Total	29	466.39200		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.8992494	0.833508	3.48	0.0017
QLT MOD closure	0.802392	0.086197	9.31	<.0001

Polynomial Fit Degree=2

AFM closure time = 1.9604057 + 0.9895043 QLT MOD closure - 0.0374995 (QLT MOD closure-8.675)^2

Summary of Fit

RSquare	0.800516
RSquare Adj	0.78574
Root Mean Square Error	1.856297
Mean of Response	9.86
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	373.35433	186.677	54.1747
Error	27	93.03767	3.446	Prob > F
C. Total	29	466.39200		<.0001

Parameter Estimates

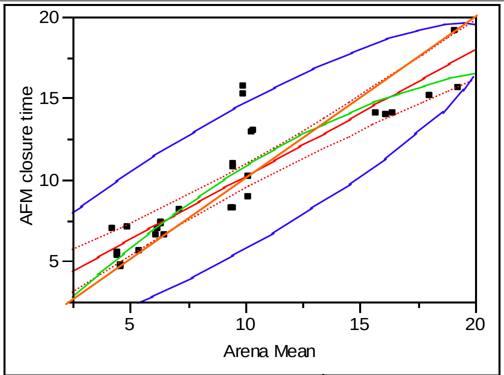
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.9604057	0.856799	2.29	0.0302
QLT MOD closure	0.9895043	0.109895	9.00	<.0001
(QLT MOD closure-8.675)^2	-0.037499	0.015241	-2.46	0.0206

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
QLT MOD closure	8.675	4.345	0.86936	0.0000	30
AFM closure time	9.86	4.010297			

Plot of AFM by Arena predicted values

Bivariate Fit of AFM closure time By Arena Mean



Linear Fit

AFM closure time = 2.5051413 + 0.7728831 Arena Mean

Summary of Fit

RSquare	0.786792
RSquare Adj	0.779177
Root Mean Square Error	1.88451
Mean of Response	9.86
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	366.95343	366.953	103.3271
Error	28	99.43857	3.551	Prob > F
C. Total	29	466.39200		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.5051413	0.801187	3.13	0.0041
Arena Mean	0.7728831	0.076034	10.16	<.0001

Polynomial Fit Degree=2

AFM closure time = 2.0336799 + 0.8844421 Arena Mean - 0.0288204 (Arena Mean-9.51613)^2

Summary of Fit

RSquare	0.80762
RSquare Adj	0.79337
Root Mean Square Error	1.822943
Mean of Response	9.86
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	376.66768	188.334	56.6738
Error	27	89.72432	3.323	Prob > F
C. Total	29	466.39200		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.0336799	0.822607	2.47	0.0200
Arena Mean	0.8844421	0.098321	9.00	<.0001
(Arena Mean-9.51613)^2	-0.02882	0.016857	-1.71	0.0988

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
Arena Mean	9.516133	4.602488	0.887013	0.0000	30
AFM closure time	9.86	4.010297			

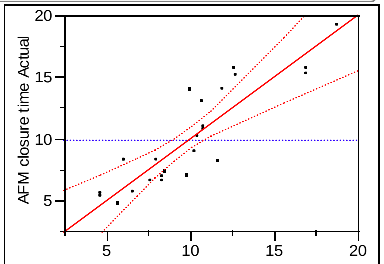
Appendix E: Meta-model Estimates

AFM Meta-model estimate

Response AFM closure time

Whole Model

Actual by Predicted Plot



AFM closure time Predicted P<.0001
RSq=0.74 RMSE=2.2291

Summary of Fit

RSquare	0.744315
RSquare Adj	0.691048
Root Mean Square Error	2.229062
Mean of Response	9.86
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	347.14278	69.4286	13.9731
Error	24	119.24922	4.9687	Prob > F
C. Total	29	466.39200		<.0001

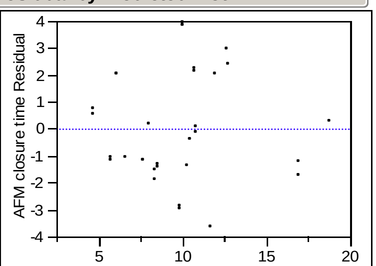
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.3132234	2.085118	0.15	0.8818
total roundtrip distance	-0.402707	0.245554	-1.64	0.1141
# enroute stops	3.2422057	0.734705	4.41	0.0002
% hot cargo	7.56	3.453248	2.19	0.0385
(# enroute stops-3.7)*(# enroute stops-3.7)	0.5950521	0.290237	2.05	0.0514
(total roundtrip distance-12.0262)*(total roundtrip distance-12.0262)	-0.065672	0.032312	-2.03	0.0533

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
total roundtrip distance	1	1	13.363734	2.6896	0.1141
# enroute stops	1	1	96.760796	19.4740	0.0002
% hot cargo	1	1	23.814000	4.7928	0.0385
# enroute stops*# enroute stops	1	1	20.885731	4.2034	0.0514
total roundtrip distance*total roundtrip distance	1	1	20.525623	4.1310	0.0533

Residual by Predicted Plot



AFM closure time Predicted

Durbin-Watson

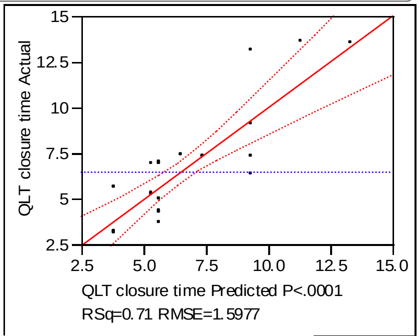
Durbin-Watson	Number of Obs.	AutoCorrelation
2.0925179	30	-0.0701

Quick Look Meta-model estimate

Response QLT closure time

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.714354
RSquare Adj	0.681394
Root Mean Square Error	1.59768
Mean of Response	6.5
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	165.97292	55.3243	21.6739
Error	26	66.36708	2.5526	Prob > F
C. Total	29	232.34000		<.0001

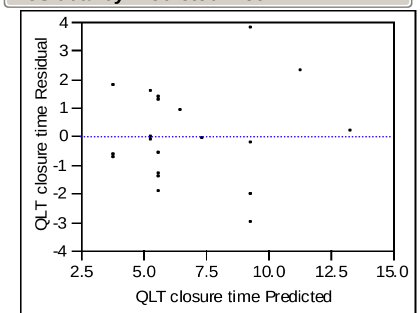
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-2.669896	1.220356	-2.19	0.0379
# enroute stops	1.2567288	0.229888	5.47	<.0001
% hot cargo	13.56	2.475115	5.48	<.0001
(# enroute stops-3.7)*(% hot cargo-0.33333)	4.4149068	1.950664	2.26	0.0322

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
# enroute stops	1	1	76.283437	29.8848	<.0001
% hot cargo	1	1	76.614000	30.0143	<.0001
# enroute stops*% hot cargo	1	1	13.075482	5.1225	0.0322

Residual by Predicted Plot



Durbin-Watson

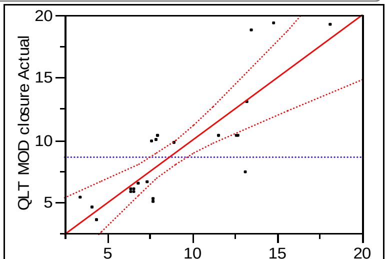
Durbin-Watson	Number of Obs.	AutoCorrelation
1.3294902	30	0.3293

Modified Quick Look Meta-model Estimate

Response QLT MOD closure

Whole Model

Actual by Predicted Plot



QLT MOD closure Predicted P<.0001
RSq=0.73 RMSE=2.4678

Summary of Fit

RSquare	0.733046
RSquare Adj	0.677431
Root Mean Square Error	2.467751
Mean of Response	8.675
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	401.33670	80.2673	13.1806
Error	24	146.15505	6.0898	Prob > F
C. Total	29	547.49175		<.0001

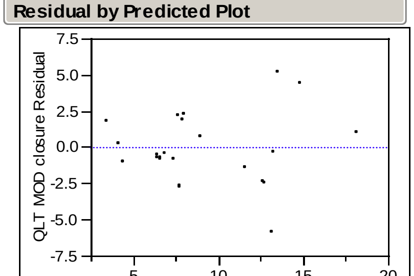
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-4.135734	2.308343	-1.79	0.0858
total roundtrip distance	-0.373461	0.267798	-1.39	0.1759
# enroute stops	2.9690558	0.785426	3.78	0.0009
% hot cargo	20.364	3.823023	5.33	<.0001
(total roundtrip distance-12.0262)*(% hot cargo-0.33333)	1.3692084	0.940823	1.46	0.1585
(total roundtrip distance-12.0262)*(total roundtrip distance-12.0262)	-0.028553	0.031427	-0.91	0.3726

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
total roundtrip distance	1	1	11.84347	1.9448	0.1759
# enroute stops	1	1	87.02187	14.2898	0.0009
% hot cargo	1	1	172.78854	28.3735	<.0001
total roundtrip distance*% hot cargo	1	1	12.89810	2.1180	0.1585
total roundtrip distance*total roundtrip distance	1	1	5.02694	0.8255	0.3726

Residual by Predicted Plot



Durbin-Watson

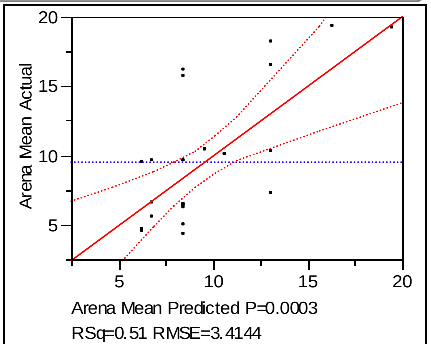
Durbin-Watson	Number of Obs.	AutoCorrelation
1.6791695	30	0.1430

Arena Meta-model estimate

Response Arena Mean

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.506564
RSquare Adj	0.449629
Root Mean Square Error	3.414449
Mean of Response	9.516133
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	311.18402	103.728	8.8972
Error	26	303.11995	11.658	Prob > F
C. Total	29	614.30397		0.0003

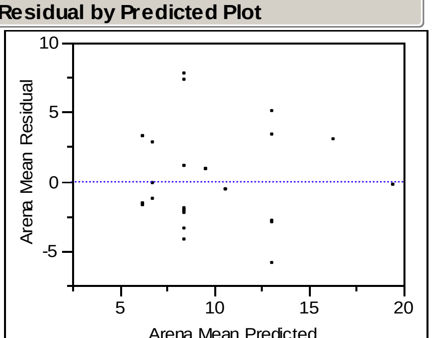
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-2.513638	2.60806	-0.96	0.3440
% hot cargo	16.1812	5.289641	3.06	0.0051
# enroute stops	1.7935238	0.4913	3.65	0.0012
(% hot cargo-0.33333)*(# enroute stops-3.7)	8.3453168	4.168821	2.00	0.0558

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
% hot cargo	1	1	109.09635	9.3577	0.0051
# enroute stops	1	1	155.36795	13.3266	0.0012
% hot cargo*# enroute stops	1	1	46.71973	4.0074	0.0558

Residual by Predicted Plot



Durbin-Watson

Durbin-Watson	Number of Obs.	AutoCorrelation
1.8699254	30	0.0611

Bibliography

Azar, Maurice. "EERISC Hot Cargo Pad Analysis." Slide presentation to European Enroute Infrastructure Steering Committee. HQ AMC/A5Y. 13 Jan 2004

Bassham, Christopher B. "Modeling PERISC Hot Cargo Pads." Slide presentation to Pacific Enroute Infrastructure Steering Committee. HQ AMC/A5Y. 16 Dec 2003

Balci, Osman. Verification, Validation, and Accreditation. Presentation to 1998 Winter Simulation Conference. Department of Computer Science, Virginia Tech, Blacksburg VA 1998. 10 March 2005 http://www.informs-cs.org/wsc98papers/006.PDF

Baudin, Michael and others. *From Spreadsheets to Simulations: A Comparison of Analysis Methods for IC Manufacturing Performance.* 1992. 12 Dec 2004 http://www.mmt-inst.com/ISMSS92_paper/imss92.htm

Bower, Aimee, John M. Halliday, and Eric Peltz. *Speed and Power.* Arlington VA: RAND, 2003.

Brigantic, Robert T. and Merril, Dave. "The Algebra of Airlift," *Mathematical and Computer Modeling, Defense Transportation: Algorithms, Models, and Applications for the 21st Century.* 649-656. New York: Elsevier, 2004

Browne, Ken S. *Using RSM, DOE, and Linear Regression to Develop a Metamodel to Predict Cargo Delivery of a Time Phased Force Deployment Document.* MS Thesis, AIFT/GOA/ENS/00-01. School of Engineering and Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 2000. (ADA378137)

Budgeting and Planning at Midsize Companies. Internal report. CFO Research Services, May 2004.

Carson, John S. *Model Verification and Validation.* Presentation to 2002 Winter Simulation Conference. Brooks-PRI Automation, Marietta GA, 2002. 10 March 2005 http://www.informs-cs.org/wsc02papers/008.pdf

Department of the Air Force. *Air Mobility Planning Factors.* AFPAM 10-1403. Washington DC: HQ USAF, 1 March 1998

Hicks, Heston R. and Lawrence L. Long. *A Methodology for Model Comparison Using the Theater Simulation of Airbase Resources and All Mobile Tactical Air Force Models.* MS thesis, AFIT/GIM/LSM/92S-24. School of Systems and Logistics, Air Force institute of Technology (AU), Wright-Patterson AFB OH, September 1992. (ADA 259683)

Granger, Julien; Ananth Krishamurthy; and Stephen M. Robinson. *Stochastic Modeling of Airlift Operations.* Presentation to the 2001 Winter Simulation Conference. Department of Industrial Engineering, University of Wisconsin-Madison, Madison WI, 2001

Jones, Seth, and others. *The Stryker Birgade Combat Team.* Arlington VA: RAND, 2002.

Lander, Chad M. and Jay Harrison. "Enhancing the Telecommunications Decision Support Process." Presentation to the IBF Telecommunications & Gas/Electric Business Forecasting Conference. n. pag. February 2000. 17 December 2004 http://www.decisioneering.com/articles/download/ibf-sprint.ppt.

Mazarr, J.M. *Light Forces and the Future of U.S. Military Strategy*. Washington DC: Brassey's (US), Inc., 1990.

Mahan, J.M., W.H. Key II, R.T. Brigantic, and K Rekamp. "Deploying the Interim Brigade Combat Team. A Quick-Look Approach for Strategic Force Closure Assessments." *Defense Transportation: Algorithms, Models, and Applications for the 21st Century*. 897-904. New York: Elsevier, 2004.

Makridakis, Spyros; Steven C. Wheelwright, and Rob J. Hyndman. *Forecasting Methods and Applications.* Hoboken NJ: John Wiley and Sons, 1998.

General Accountability Office. *Military Transfromation*: *Realistic Deployment Timelines Needed for Army Stryker Brigades.* Report number GAO-03-801. Washington: Government Printing Office, 2003. 12 February 2004 http://www.gao.gov/new.items/d03801.pdf

Pektas, Mustafa K. *Quicklook Air Mobility Modeling.* MS Thesis, AFIT/GLM/ENS/02-14. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 2002. (ADA400200)

Pelletier, Dana C. *Probability Distribution Analysis of Air Mobility Planning Factors.* Graduate Research Project, AFIT/MLM/ENS/04-08. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 2004.

Reckamp, K. and others. "Interim Brigade Combat Team Air Mobility Deployment Analysis." Report to Lieutenant General D. Brown, US Army, United States Transportation Command, Scott AFB IL, 2002.

Stucker, Joseph P. and Leann Melody Williams. *Analyzing the Effects of Airfield Resources on Airlift Capacity*. Washington DC: RAND, 1994.

Vita

Captain Matthew M. Gill graduated from Tyrone Area High School in Tyrone, Pennsylvania. He entered undergraduate studies at the Pennsylvania State University in University Park, Pennsylvania where he was a member of the University Scholars honors program and graduated with a Bachelor of Science degree in Mathematics in May 1999. He was commissioned through Detachment 720 AFROTC at the Pennsylvania State University.

His first assignment was at Tinker AFB as a Logistics Plans officer serving as the Wing Deployment Officer for Air Combat Command's (ACC) 552 Air Control Wing, the CONUS home of 28 Airborne Warning and Control System aircraft. While serving at Tinker, he was repeatedly recognized for his outstanding performance, including personal recognition by the ACC Inspector General during a 2001 Unit Compliance Inspection.

His next assignment was at Royal Air Force, Mildenhall where he served as a group director of logistics for the 352 Special Operations Group, USEUCOM's Air Commandos. During this time, he deployed throughout the European theater in support of several contingency operations, including Operations Northern Watch, Iraqi Freedom, and Autumn Return, during which he served as the J-4 for the task force.

In August 2003, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon completion of his program, he will be assigned to Headquarters Air Mobility Command at Scott AFB, IL.

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14. ABSTRACT

This research explores the changes in insights resulting from using different types of models to assess the capability of deploying the Stryker Brigade within specific timeline goals. This research uses as its primary base one study conducted in 2002 by USTRANSCOM to evaluate the ability of Stryker to meet stated deployment timeline goals. Specifically, this thesis compares the outputs from four different models as they changes over three different deployment scenarios and ten different routes. This research investigates the relationships among the outputs of spreadsheet models, spreadsheet models with elements of variability added, and low- and high- level discrete event simulations. This research also explores the implications of applying newly proposed distributions describing the variability in aircraft cargo loads and en route ground times.

The results of this research suggest that the type of model used to assess a deployment does indeed have an effect on the insights derived from exploring scenarios. This work also suggests that the newly proposed ground time distributions have a significant effect on the ability to move cargo through an en route system and also suggests what factors have the greatest limiting effect on the ability of Stryker to meet its deployment timeline goals.

15. SUBJECT TERMS

Spreadsheet Models, Discrete-event Models, Deployment Models, Model Comparisons, Stryker Brigade, Arena, Crystal Ball

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